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EUTROPHICATION OF LAKE TAHOE EMPHASIZING WATER QUALITY

Charles R. Goldman

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16. ABSTRACT

A 4 1/2-year study on the rate and factors affecting the cultural eutrophication of oligotrophic Lake Tahoe is reported. Primary productivity has increased alarmingly with a steady shift in the seasonal maximum from early spring to late summer. Productivity increased 25.6% from 1968 to 1971. Using the 1959-1960 data from earlier studies, the increase to 1971 was 51%. Diatoms dominate the phytoplankton population and the maximum zone of phytoplankton photosynthesis may be as deep as 50-75 m. The extent of winter mixing is important in the nutrient budget of the lake and bacteria associated with stream-borne nutrients facilitate nutrient regeneration. The littoral zone, although extremely important visually to the lake, contributes only 10% of the total primary production. Great variability in fertility of the lake has been demonstrated by synoptic studies and aerial remote sensing. Highest productivity is found in the lake near tributaries which drain disturbed land. Nutrients associated with road building, housing, and lumbering are major causes of eutrophication in Tahoe. In bioassay studies NTA was found to stimulate primary productivity. Drainage from a sewage land disposal site continues to yield high levels of nitrate, and marinas may serve as nutrient and sediment traps or as eutrophic, isolated systems. Daphnia, an mportant cladoceran component of the zooplankton population has virtually disappeared rom the lake and predation by the introduced zooplankter Mysis relicta and the okanee salmon are suspect.

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December 1974

EUTROPHICATION OF LAKE TAHOE
EMPHASIZING WATER QUALITY

by

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ABSTRACT

A 4 1/2-year study on the rate and factors affecting the cultural eutrophication of oligotrophic Lake Tahoe is reported. Primary productivity increased alarmingly during the investigation with a steady shift in the seasonal maximum from early spring to late summer. Productivity increased 25.6% from 1968 to 1971. Using the 1959-1960 data from earlier studies, the increase to 1971 was 51%. Diatoms dominate the phytoplankton population and the maximum zone of phytoplankton photosynthesis may be as deep as 50-75 m. The extent of winter mixing is important in the nutrient budget of the lake and bacteria associated with stream-borne nutrients facilitate nutrient regeneration. The littoral zone, although extremely important visually to the lake, contributes only 10% of the total primary production. Great variability in fertility of the lake has been investigated by synoptic studies and aerial remote sensing. Highest productivity is found in the lake where tributaries drain disturbed land. Nutrients associated with road building, housing, and lumbering are now major causes of eutrophication in Lake Tahoe. In special bioassay studies, it was found that NTA stimulates primary productivity, drainage from a sewage land disposal site continues to yield high levels of nitrate, and marinas may serve as nutrient and sediment traps or as very eutrophic isolated systems. The important cladoceran component of the zooplankton population has virtually disappeared from the lake and predation by the introduced zooplankter Mysis relicta and the kokanee salmon are suspect. Crayfish are the dominant members of the benthic animal community which deserve particular attention as scavengers of the littoral zone.

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SECTION I

CONCLUSIONS

1. Despite accelerated eutrophication over the last 15 years, Lake Tahoe is still one of the most oligotrophic lakes in the world. Because of its clear waters, active photosynthesis extends to depths of over 100 m. The depth at which maximum primary productivity occurs may be as deep as 50-75 m, and attached plants live to depths of over 100 m. The distribution of primary productivity with depth evolves from a simple unimodal curve during winter and spring to a bimodal curve in summer and fall.

2. Measurements of primary productivity with ^{14}Carbon are by far the most sensitive indicators of changing fertility in Lake Tahoe. Based on about 6,200 samples, the annual productivity of Tahoe has shown a steady and alarming increase from year-to-year over the 4 1/2 years covered in this report. The best available productivity data cover the time interval from 1968 to 1971. During this period productivity increased 25.6%. Using the 1959-1960 data, the increase to 1968 was about 20% and to 1971 was 51%. Considering the entire 1967-1971 period, the seasonal maximum of productivity has shifted steadily from early spring in 1968 to late summer in 1971.

3. The lake has received increasing nutrient and sediment input from a number of its influent tributaries as a result of accelerated road

building and construction in the basin. Synoptic surveys of aereal variation in fertility indicate the relatively high productivity of the littoral zone and the steady increase in the productivity of the pelagic zone relative to the littoral. Emerald Bay is the most productive part of the lake proper and stations off Bijou, Incline Creek, Dollar Point, and the Upper Truckee River gave particularly high productivity values. Sediment plumes delineated by aerial photography and simultaneously sampled for 'water truth' demonstrated the importance of spring inflow to increasing the productivity of Tahoe's surface waters. The more disturbed the watershed, the greater the output of such algal growth-promoting nutrients as nitrogen, phosphorus, and iron. An abandoned land disposal site for sprayed sewage effluent continues to yield high concentrations of nitrate to Heavenly Valley Creek several years after application.

4. To the largely shore-based human population, the littoral zone is a highly visible and important part of the lake. Despite the relatively high fertility of Tahoe's littoral zone, it constitutes a small percentage of the lake's area, because of its great depth and steep contours. The littoral zone contributes only about 10% of the lake's total primary production. To the organisms that inhabit the lake, the littoral zone is highly important for food, cover, and reproduction.

5. Measurement of heterotrophic growth in Tahoe has been particularly valuable in relation to sediment input. The bacteria are extremely important in nutrient regeneration and their growth is consistently stimulated by sediment. Even nutrient-stripped sediment provides a substrata for bacterial growth.

6. The degree of winter mixing is particularly important in distributing available nutrients, particularly nitrate, from the depths of

Tahoe back into the euphotic zone. This is probably a key factor in year-to-year variation in productivity.

7. Nitrogen, phosphorus, iron, silicon, and particulate and inorganic carbon were measured routinely during the course of the study. Phosphorus is more uniformly distributed than nitrate which forms a distinct nitrocline. This gradient in nitrate concentration is particularly valuable as a marker in determining the depth of winter mixing. Ammonia is found at vanishingly low levels and deionized water blanks were often higher than the lake water. Nitrate concentrations are generally as low as or lower than total phosphorus. Near shore areas are typically higher than deep water stations in both phosphorus and nitrogen and show greater seasonal variation. Particulate carbon in lake waters averaged about 50 $\mu g \cdot l^{-1}$ and inorganic carbon about 10 $\mu g \cdot l^{-1}$ with fairly high uniformity.

8. Significant stimulation of photosynthesis was observed in experiments with additions of NTA at low concentrations. The response to NTA additions was greatest in waters of low inorganic nitrogen content. In addition to perhaps supplementing the direct nitrogen requirements of the lake's natural phytoplankton populations, the chelation properties of NTA may increase the availability of other necessary and perhaps limiting trace elements.

9. There are over 160 species of phytoplankton in Lake Tahoe of which 112 are diatoms. Only 10 are centric forms and the rest are pennate. Cyclotella bodanica and Melosira crenulata are dominant centric diatoms while Fragilaria crotonensis is the most important pennate. These three oligotrophic forms account for about 80% of the phytoplankton biomass throughout most of the year.

10. The Lake Tahoe zooplankton community has undergone a transition in dominance with the virtual elimination of cladocerans as a major phytoplankton grazer. The cladoceran disappearance may be related to introduction of two new predators. *Mysis relicta*, the opossum shrimp, has become well established and may be an important predator on cladocerans. *Oncorhynchus nerka*, the land-locked red salmon called "kokanee", is also a major predator on cladocerans and may have contributed to their disappearance from the plankton.

11. Marinas may serve as nutrient and sediment traps if their tributaries are polluted. Because marinas have limited circulation, they have their own special problems of eutrophication. The large Tahoe Keys development at South Shore was found to be from 3.4 to 19.2 times more productive than the richest area of the lake. Star Harbor at the north shore reduces the nutrient and sediment load of its polluted tributaries and grows large quantities of periphyton.

12. The single most important benthic organism is the California crayfish *Pacifastacus leniusculus*. These abundant scavengers are important in grazing the littoral zone of Lake Tahoe and have served as brood stock to re-establish an important industry in northern Europe that has been gradually destroyed by a plague to which the California crayfish is highly resistant.

SECTION II

RECOMMENDATIONS

The following recommendations are based on the research included in this report and are pointed towards the central objective of maintaining the water quality and aesthetic values that have given Lake Tahoe its international reputation as one of the clearest and most beautiful lakes in the world. Recommendations are also directed towards the research that still needs to be accomplished or data that will require further evaluation and interpretation.

1. Reducing sediment yield from the watershed with its associated nutrients should be a major component for planning, management, and enforcement in the basin. Additional studies on erodibility, weathering, and hydrology are particularly desirable. Water levels in the lake should be maintained by the Water Master at a lower level than the near flood stage conditions of maximum storage to reduce beach and shore erosion. The physical process of wind mixing in winter is of extraordinary importance to the economy of the lake's nutrient regime and deserves continued attention.

2. Atmospheric sources of nitrogen are important to Lake Tahoe and the quantitative role of denitrification in the lake and on the watershed needs further clarification.

3. General monitoring of the chemical content of Tahoe's offshore waters was the least productive of the Tahoe limnological research efforts. Few chemical laboratories are able to routinely maintain the precision necessary for reproducible results at the extremely low levels encountered. Tributary and near shore waters require the most attention, and nitrogen, iron, and, to a lesser degree, phosphorus are currently the nutrients most limiting to algal growth in Tahoe.

4. Measurements of primary productivity in Tahoe together with measures of heterotrophy remain the most important and sensitive indicators of eutrophication in the lake. Without them, the basis for recognizing the rate of eutrophication and point sources of greatest fertilizing influence would be lost. These measures which began in 1959 provide a highly sensitive and important integration of the biology, physics, and chemistry of the lake and should be continued indefinitely in any ongoing research program at Tahoe.

5. Synoptic sampling combined with aerial photography has clearly delineated the problem areas in the lake. Special attention should continue to be given to the Upper Truckee River, Incline, Third, Burton, and Taylor Creeks. Monitoring of General Creek should be continued as a control for the more intensive studies on Ward Creek before, during, and after its development.

6. Bioassay experiments emphasize the great importance of nitrogen and iron and, to a lesser extent, phosphorus in the algal growth in Tahoe. Efforts should be directed toward keeping these nutrients

at limiting levels in the lake.

7. NTA is a potent biostimulant for algal growth in Tahoe and should not be permitted in the basin.

8. Land disposal of treated sewage as it was practiced on the Heavenly Valley Creek watershed should never again be permitted. This area, years after disposal has ceased, continues to yield the highest levels of nitrate of any drainage in the basin. Nitrogen in ground water may prove of considerable importance in the basin and new studies should be directed towards this problem. Nitrogen stripping as ammonia in tertiary treatment may require further evaluation.

9. The role of bacterial regeneration of nutrients in the process of eutrophication is becoming more clear. Continued research in this area should be encouraged.

10. Periphyton, abundant in the littoral zone and along tributary stream courses, has first access to stream-borne nutrients and continues to be of importance to the economy of the lake. Although contributing only about 10% of the primary productivity, attached algae in the littoral zone provide the greatest visual evidence of the lake's deterioration to the largely land-bound resident and tourist. The dynamics of attached algal growth will require continued study. The possibility that the resident crayfish population provides a measure of control also merits further study.

11. The disappearance of some components of the zooplankton population requires further attention. The quantitative trophic relationships between bacteria, detritus, phytoplankton, zooplankton, and fish need further elaboration. Studies directed toward Daphnia predation by kokanee (Oncorhynchus nerka) and perhaps Mysis are

necessary.

12. Marinas have a complicated relationship to the lake. They may actually improve the water quality of polluted or sediment-laden streams by serving to strip nutrients through periphyton and planktonic algal growth and settle out sediment derived from drainage. The construction phase is the most potentially damaging and should be carefully evaluated and controlled.

SECTION III

INTRODUCTION

Lake Tahoe lies at an altitude of 1898 m in the Sierra Nevada. It is a large (499 km^2), deep, subalpine lake, formed in a graben fault, with a maximum depth of 501 m. The lake basin has steep sides, a flat bottom, and very little shallow water for its size (Fig. 1). The average depth of the lake is 313 m and its shoreline covers 113 km. Lake Tahoe is particularly renowned among the lakes of the world for its great transparency and the beauty of its deep blue color (Smith, Tyler, and Goldman 1973). Mean monthly Secchi depth readings to 40 m have been recorded in the winter months and the compensation depth (where photosynthesis equals respiration) is found at about 105 m. In this extraordinarily clear lake the littoral zone extends to a depth of 100 m. Because of its steep basin, this represents only 18.7% of the surface area of the lake. This narrow band of shallow water has, however, great importance to the many users of the lake and provides the main visual evidence of water quality to the largely shore-bound populace.

Lake Tahoe is unquestionably changing and it has been towards quantifying and slowing this change that the research reported here has been directed. During the last few decades there has been a dramatic population increase in the Tahoe basin and signs of accelerating eutrophication are now clearly discernible. In spite of the lake's great volume for dilution, local nutrient sources are altering the productivity

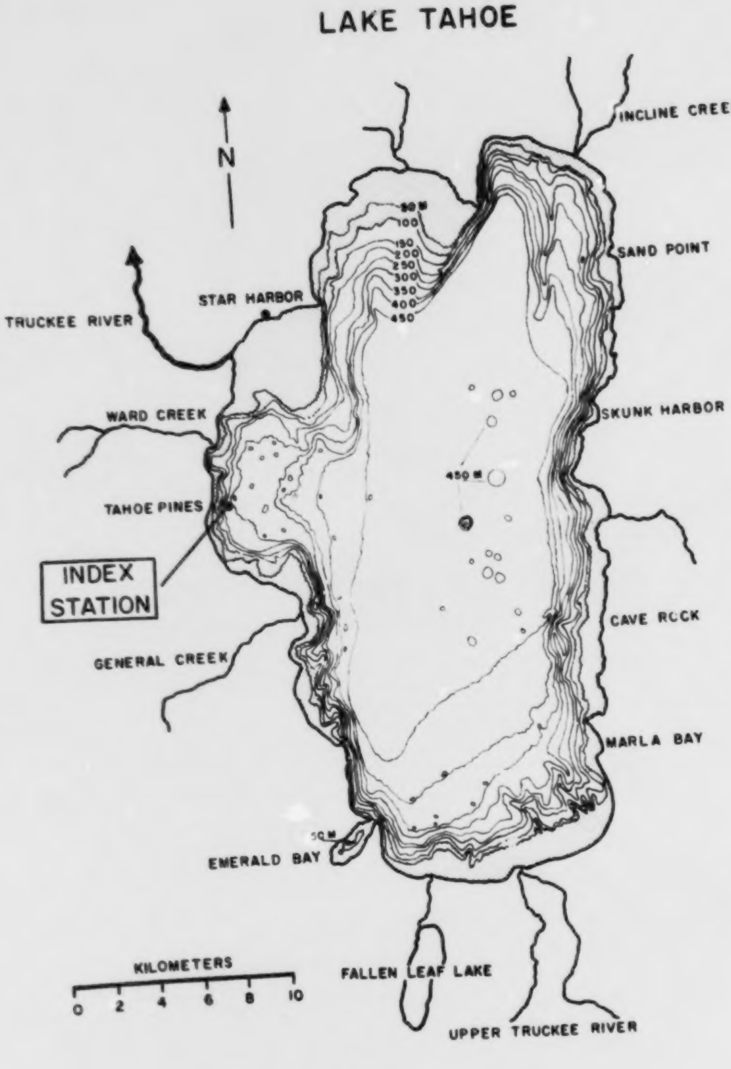
LAKE TAHOE
N
INCLINE CREEK
50 M
100
150
200
250
300
350
400
450
SAND POINT
STAR HARBOR
TRUCKEE RIVER
SKUNK HARBOR
WARD CREEK
450 M
TAHOE PINES
INDEX STATION
CAVE ROCK
GENERAL CREEK
MARLA BAY
50 M
EMERALD BAY
KILOMETERS
0
2
4
6
8
10
FALLEN LEAF LAKE
UPPER TRUCKEE RIVER

Figure 1. Bathymetric map of Lake Tahoe indicating the index station and other locations. The contour interval is 50 m. The shaded area indicates the littoral zone which extends to 100 m depth.

pattern around the lake. Aerial photographs taken since 1967 show spectacular local increases of turbidity due to the inflow of sediments and nutrients from tributaries of disturbed watersheds. As the human population continues to increase in the Tahoe basin with a concommitant rise in construction activities--lumbering, road building, housing developments--serious damage to the watershed of the lake has resulted. This exposure of mineral soil to erosion and the resulting leaching out of nutrients is causing a cultural eutrophication of the lake. Large plumes of sediment from tributary streams and the appearance of luxuriant growths of attached algae around the entire margin of the lake were the first really visible signs of change. The first spring algal bloom that was observed appeared off South Shore in 1969, thus providing the residents and tourists alike visible evidence of a general increase in fertility.

During the past 15 years Lake Tahoe has been the subject of intensive limnological research with emphasis on the lake's primary productivity, nutrient limiting factors, and the process of eutrophication (Goldman and Carter 1965, Goldman and Armstrong 1969, Goldman 1972). Since 1959 measurements of primary productivity have been made in the lake as part of a series of northern California lake investigations on nutrient limiting factors (Goldman 1964). These investigations of photosynthesis by phytoplankton have provided an important index of the fertility of the lake and, perhaps of greatest importance, have established a particularly valuable base line for determining the extent and rate at which eutrophication is progressing. During the period from mid-1967 through 1971 the research program was greatly expanded with an FWQA (now EPA) Grant #16010 DBU. The continued and expanded surveillance of primary production within Lake Tahoe provides a quantitative evaluation of long-term eutrophication trends in Lake Tahoe together with a better understanding of the processes involved.

RESEARCH PROGRAM

Since 1967 routine weekly to trimonthly sampling at the index station located near the western shore of the lake (Fig. 1) has been made involving measurements of primary productivity with the sensitive ^{14}C method, collection and enumeration of zooplankton and phytoplankton, phosphorus, nitrogen, and particulate carbon concentrations. Data collected at the index station has provided a nearly continuous record of photosynthetic rates along with ancillary limnological information. The value of this phase of the research increases as the data accumulates, since it forms the basis for long-term analysis of the rate of Lake Tahoe's eutrophication. There is strong evidence that the fertility of the lake has increased by about 50% in the last decade and by about 25% during the four years of study covered by this report.

One of the most valuable techniques of locating areas of high production within Lake Tahoe developed during the studies is simultaneous collection, incubation, and analysis of samples taken during synoptic cruises. The synoptic approach has greatly improved our evaluation of cultural eutrophication, since it has enabled the investigator to accurately locate the most important sources of nutrients before the entire lake has undergone change. Contour mapping of synoptic primary production data generally indicates a positive correlation between intensive land development and higher production rates (Goldman, Moshiri, and Amezaga 1972).

Synoptic studies also clearly evidence the higher fertility of the lake near areas of population build-up and where streams are delivering a high nutrient load to the lake. Such areas of increased fertility have been discovered at the south shore of the lake under the influence of the Upper Truckee River drainage and high resident population, in Crystal Bay where Incline and Third Creeks drain highly disturbed land, and near the outflow of the lake where there is both a high resident population and fairly extensive areas of shallow water (Goldman and Carter 1965). These studies continue to provide a feasible rationale for predicting changes occurring in the lake as a result of watershed development with associated natural and polluted drainage (see Section VII).

In investigations of the sources of eutrophicating substances, Lake Tahoe's tributaries have been shown to be of paramount importance. Their biostimulatory effect upon the lake has been documented using the ^{14}C-bioassay technique (Goldman 1963) in combined stream and lake water cultures. In 1968 productivity measurements were routinely made at the mouths of influent streams draining culturally disturbed regions of the lake's basin (Upper Truckee River and Incline Creek). The results of these experiments are described in detail in Goldman and Armstrong (1969) where it was shown conclusively that the lake is heavily influenced by stream water from disturbed land areas. This influence was far greater than that observed off the mouth of a control stream draining relatively undisturbed land (General Creek). The measurements further indicate that it is primarily the nutrient loads in the sediments carried by the streams from disturbed watersheds which can be stimulatory to algal growth. One such measurement on 12 August 1969, following the disturbance of Third Creek during construction of a golf course, resulted in the highest stimulation ever encountered in similar experiments from a variety of tributaries in the Tahoe basin (Goldman, Moshiri, and Amezaga 1972). Third Creek effluent stimulated growth by 620% over controls. This quite dramatically revealed the influence of drainage from freshly exposed soils on the growth of algae in Lake Tahoe. Clearly these investigations substantiate previous indications of considerable cultural eutrophication occurring in Lake Tahoe's water from disturbed land areas. Further, they have helped provide a basis for new zoning ordinances proposed by the Tahoe Regional Planning Agency (see Section VII).

A study of the bottom sediments of Lake Tahoe was undertaken in order to evaluate the extent of sediment pollution of the lake resulting from increased land disturbance within the Tahoe basin as well as to determine the extent of areal variability in the sediment types. Examination of bottom surface sediments collected on a grid system covering the whole lake has revealed that there are two major types of sediment present: pollen-rich diatomaceous ooze typical of passive fluvial erosion deposits and sediments resulting from rapid erosion and slumping into deeper parts of the lake typical of exposed products of glaciated rocks (Court, Goldman, and Hyne 1972). The types of pollen found in bottom samples have been analyzed as well as their possible role as a source of nitrogen and phosphorus to the lake (Richerson, Moshiri, and Godshalk 1970). The studies also indicate that high concentrations of suspended matter in tributaries result from erosion in areas of extensive land development (see Section IV).

Research was also conducted on two man-made marinas at Lake Tahoe. The large Tahoe Keys marina at South Shore is about three times as productive as Lake Tahoe. It has been isolated from the lake, except for a small channel to the lake, in a former swampy area. In the much smaller Star Harbor, primary productivity was found to closely follow the concentration of iron during the year. Results showed a highly significant positive correlation between iron concentration and primary productivity. In bioassay culture experiments, additions of iron in concentrations of 25 $\mu g \cdot l^{-1}$ or more were found to definitely stimulate the growth of algae in Star Harbor water. In biostimulation cultures neither of the two streams flowing into the harbor significantly stimulated productivity in the harbor, but both streams stimulated the productivity of Lake Tahoe water. Although Star Harbor serves as a sediment and nutrient trap, its waters still have some biostimulatory effect on the water of Lake Tahoe (Coil 1971) (see Section XII).

Work has continued on the delineation of Lake Tahoe's morphometry. Such studies are designed to reveal details of the geology and geomorphology of the Tahoe basin and have involved our cooperation with geologists and geophysicists. Investigations using a large piston corer for extraction of 6 m cores, a bottom sounding air gun for recording the depth and extent of sediment layers, a magnetometer for determination of basement rock fractures, submerged fault scarps, and magnetic anomalies, and data taken from fathometer transects have resulted in the production of a detailed bathymetric map of the basin and in increased knowledge of its geological history (Hyne et al. 1972).

A submarine mountain (lake mount) rising 7.6 m above the lake floor has been discovered and described by Goldman and Court (1968). Since the initial studies, the lake mount has been more accurately located by several transects over it to obtain a three-dimensional outline, and formulae have been derived for computer application. Corrected slope profiles were then used to plot an accurate contour map. Periodic fathometer readings continue to be taken to further our explorations of the bottom features of this unusual lake (see Section IV).

A cluster analysis was used in an investigation of the community ecology of both the zooplankton and phytoplankton to determine the spatio-temporal structure of the Tahoe plankton. These investigations revealed that phytoplankton are more loosely clustered than the animal portions of the community and support the notion that the phytoplankton are a non-equilibrium assemblage in apparent violation of the competitive exclusion principle (Richerson, Armstrong, and Goldman 1970). An analysis of the summary statistics and other data indicated that spatial heterogeneity was at least as important as temporal differences in generating the observed diversity of phytoplankton.

Combined phytoplankton-zooplankton clusters showed that these two portions of the community were structurally independent and consequently subtle differences in food preferences have no demonstrable effect upon the diversity of the zooplankton (Richerson 1969). Phytoplankton diversity was found to be positively associated with both high turnover rates and zooplankton grazing. The model postulated is that zooplankton reduce phytoplankton biomass but increase turnover rate, thus admitting more species to the assemblage. The disappearance during the course of our investigation of an important zooplankter Daphnia rosea may have important implications for phytoplankton grazing and fish food supply in the lake.

The crayfish Pacifasticus leniusculus has been the subject of research since 1968 in Lake Tahoe. The size, structure, density, seasonal and diurnal migration, and reproductive characteristics of populations has been determined (Abrahamsson and Goldman 1970, Goldman 1973). Field and laboratory studies of crayfish diet and feeding habits have been coupled with respiratory metabolism to establish the energy relationships of the organism (Moshiri and Goldman 1969; Moshiri et al. 1970, 1971). Subsidiary studies were also initiated on their abundance and characteristics in nearby Donner and Fallen Leaf lakes. As a result of these studies, this crayfish is being introduced to Swedish lakes and rivers by the Swedish Fishery Board to replace native species destroyed by an epidemic. The crayfish research resulted not only in research and publication concerning the physiology and breeding habits of Pacifasticus but, perhaps more significantly, was instrumental in promoting international goodwill and cooperation between Sweden and the United States (see Section XI).

The ^{14}C-bioassay technique described by Goldman (1963) has been used in monthly experiments to determine nutrient deficiencies of the lake and has demonstrated the relatively greater potential of nitrogen for increasing the growth of Tahoe phytoplankton as compared with phosphorus. Nitrate additions to cultures of Tahoe water were found to stimulate phytoplankton growth. Additional phosphate research has indicated that phosphorus concentrations are already adequate to support greater standing crops of algae if additional nitrogen and iron are provided (Goldman, Tunzi, and Armstrong 1969). Additional phosphate does provide for stimulation of algal growth with added nitrate so that nitrate-phosphate supplies interact to promote added growth. Even when maximum response to added phosphorus was obtained, the magnitude of response was far less than that observed during incubation of pelagic lake water with 1% additions of stream water. The stimulatory effect of stream water cannot be attributed to the phosphorus content alone, since this is seldom more than three times that of the lake itself. The stimulatory effect of streams is largely from nitrate and iron and is related to some component, presumably a dissolved organic compound, of stream water having a high absorbance in the ultraviolet (Goldman and Armstrong 1969). This water is peculiar to the Upper Truckee River which provides about 40% of the lake's inflow, and has a high bacterial activity as measured by ^{14}C-acetate uptake (Paerl and Goldman 1972a) (see Section VII).

Investigation of a former land disposal site at Lake Tahoe indicates that nitrogen continues to leach from the area. Many years after the spraying of secondary effluent ceased (see Section VII) Heavenly Valley Creek, which drains the area, continues to be the most polluted stream in the basin.

Sampling in 1968 of the rate of attached algal colonization on glass cylinders has demonstrated the utility of this technique as an excellent means for the detection of enriched water masses. Data gathered from periphyton samples indicate, as did the primary productivity information gathered from simultaneous synoptic cruise collection, accelerated growth in certain areas within the lake (Goldman, Moshiri, and Amezaga 1972). Duplicate sets of glass cylinders were collected from 79 stations around the lake shore. One set was used for biomass determination (Armstrong, Goldman, and Fujita 1971) and the second set was preserved for species identification and enumeration. The information derived from these studies has produced an extensive list including over 130 individual species of periphyton. The importance of the shallow water production has been evaluated by Goldman and Amezaga (1974) (see Section IX).

In 1962 a series of determinations of oxygen concentration at depths from the surface to the sediment-water interface were initiated. Measurements since then have revealed no evidence of oxygen depletion at the sediment-water interface and only slight variations in concentration with depth. With the acquisition of high quality reversing thermometers and frames, a bimonthly sampling of oxygen and temperature to a depth of nearly 450 m was instituted. The data derived from these samples enabled computation of temperature and oxygen budgets with greater accuracy and examination of the problem of vertical mixing within the lake. The assemblage of this data provides a base line, thereby facilitating the detection of changes accompanying future eutrophication. Interest in deep water limnology has increased through the cooperative activities of the Marine Food Chain Group from Scripps Institution of Oceanography at the University of California at La Jolla (Holm-Hansen et al. unpublished) (see Sections IV and V).

Towards the end of four years of study our attention was directed toward a consideration of the role of bacteria in Tahoe eutrophication. We intensified our activity in this area since we recognized the probable importance of bacteria associated with sediment entering the lake. In conducting the heterotrophic study of Lake Tahoe we have been able to plot the paths of certain water masses originating from polluted streams (Paerl and Goldman 1972a). By using an extremely sensitive method for detecting the water mass originating from streams and measuring their stimulatory effect on the lake bacterial populations, we have been able to delineate the extent of a eutrophicating stream flow. The procedure involved in these studies utilizes bacterial uptake of trace amounts of ^{14}C dissolved organic substrates which were found to be an excellent measurement of heterotrophy. The microbial incorporation of 2-^{14}C-acetate is monitored and converted to ^{14}C-acetate assimilation rates. This approach clearly demonstrates the heterogeneity of water masses, particularly those originating from disturbed watersheds. This technique has enabled us to determine the relative importance of individual inflows on the lake's fertility (Goldman et al. 1974).

To substantiate the fact that bacterial uptake, is, in fact, being measured, autoradiographic techniques were employed to locate the tracers among algal and bacterial populations. ^{14}C and ^{3}H autoradiographic evidence indicates that bacteria were largely responsible for ^{14}C-acetate uptake during incubation while algal cells failed to show acetate incorporation. This work has subsequently been extended by use of the scanning electron microscope (Paerl 1974).

The year-round study of heterotrophy and primary production has shown how these processes complement one another since both show similar seasonal cycles. After monitoring changes in rates of heterotrophic uptake of acetate for one year using monthly sampling on both a horizontal (18 stations in Tahoe) and a vertical scale (0 to 105 m depth), increases in both heterotrophic population and activity were found to follow algal blooms both temporally and spatially. When the algal population begins to decrease in activity, the heterotrophic population may increase tenfold in assimilation rate of acetate and other organic compounds. This, as well as increased creek inflow and siltation in the spring and summer months, is being linked with increased bacterial cycling in the slowly warming water column (Paerl and Goldman 1972b).

Siltation in itself appears to be extremely important with regard to accelerating bacterial growth in Lake Tahoe. Autoradiographs and scanning electron microscopy have shown that silt particles offer good substrate and attachment sites for actively growing bacteria which further suggests the importance of siltation in eutrophication (Paerl and Goldman 1972b) (see Section VIII).

During the 1967-71 period of research, certain innovations and modifications of experimental procedures have been developed which greatly facilitated the research and should prove particulary valuable to future investigations. A method for measuring particulate carbon and the carbon content of periphyton was developed which employs combustion of samples in an induction furnace and measuring their carbon dioxide content with an infrared carbon dioxide analyzer (Armstrong, Goldman, and Fujita 1971). The refinement of the earlier synoptic approach has enabled more precise productivity measurements and determination with greater accuracy of the areal variation in Lake Tahoe's fertility (Goldman, Moshiri, and Amezaga 1972). A bacterial activity assay procedure has been developed by Paerl and Goldman (1972a) for detecting water masses in Lake Tahoe. Autoradiography and scanning electron microscopy have been utilized also to observe bacterial attachment to substrates (Paerl and Goldman 1972b). Holm-Hansen and Paerl (1972) have applied ATP methods to estimate microbial biomass and metabolic activity. The transect work provided "water truth" for a remote sensing study with NASA-Ames of the Upper Truckee River sediment plume (Goldman et al. 1974).

RELATIONSHIP OF EPA STUDY TO OTHER PROJECTS AND ONGOING RESEARCH

It is obvious from the previous pages of this report that a great deal of the information presented here on the general limnology and the eutrophication of Lake Tahoe has already been compiled and published. It was also apparent that the significance of much of that work was that it has provided the essential background of data to use as a baseline for further study and to provide a cornerstone for policy making decisions that are so necessary for the protection of the Tahoe environment.

Of great importance to the U.C. Davis limnological studies described in this report has been our interaction and cooperative research efforts with many other groups, agencies, and individual scientists working at Tahoe. Figure 2 indicates the cooperative relationships between the University of California, Davis, Limnology Group and other agencies and institutions involved in Tahoe basin studies. A series of descriptions of these cooperative efforts follows which details the extent of these interactions. The limnological work that was begun with EPA funding is to a large degree being continued with different emphasis through NSF-RANN support. The exact point where support from the first ceased and the second began is of less importance than the fact that the general continuity of research activity survived.

Environmental Protection Agency

Dr. Goldman has been involved in consultation on eutrophication research with EPA-Corvallis and the EPA-WERL Group at Las Vegas. A report was submitted to EPA on the effects of NTA on natural phytoplankton populations in Tahoe, Castle, and Clear Lake (Goldman and Fujita 1970). Three years of Lake Tahoe and tributary stream water chemistry data was provided the EPA-San Francisco office for its data bank. Robert

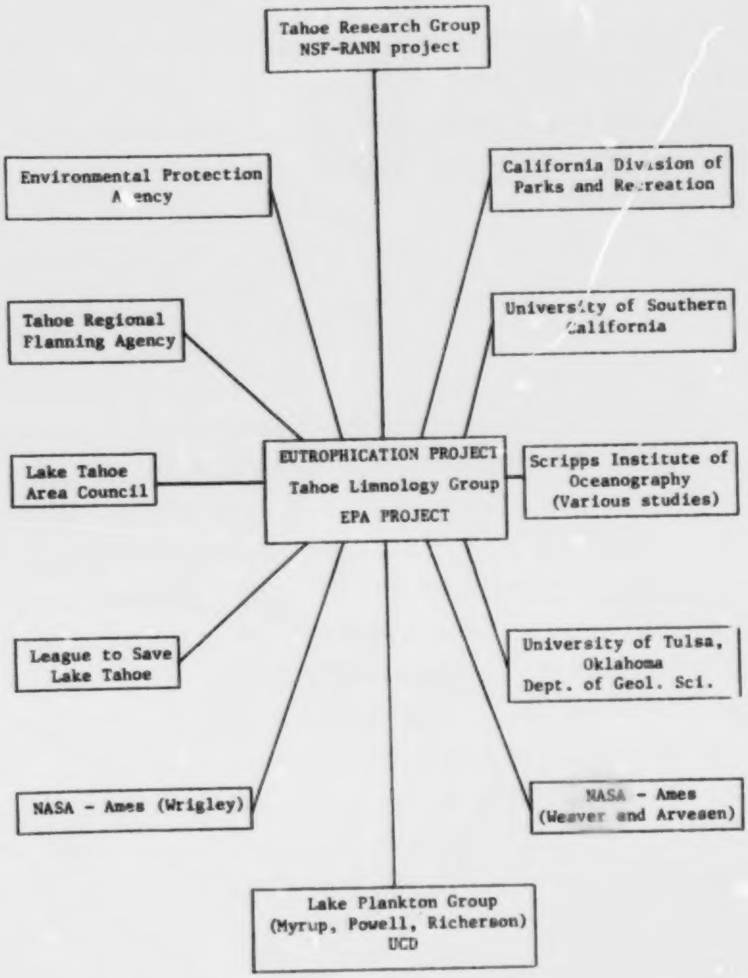
Tahoe Research Group
NSF-RANN project
Environmental Protection Agency
California Division of Parks and Recreation
Tahoe Regional Planning Agency
University of Southern California
Lake Tahoe Area Council
EUTROPHICATION PROJECT
Tahoe Limnology Group
EPA PROJECT
Scripps Institute of Oceanography (Various studies)
League to Save Lake Tahoe
University of Tulsa, Oklahoma Dept. of Geol. Sci.
NASA - Ames (Wrigley)
NASA - Ames (Weaver and Arvesen)
Lake Plankton Group (Myrup, Powell, Richerson) UCD

Figure 2. Cooperative relationships between the University of California, Davis, Limnology Group and other agencies and institutions involved in Tahoe basin studies.

Richards and Hans Paerl recently carried out a small study of the effects of taconite disposal in Lake Superior for EPA using biological assay techniques employed routinely in Lake Tahoe studies (1971). The principal investigator provided expert testimony during the court trial in Minnesota. Dr. Goldman visited Lake Baikal in the USSR with an EPA-sponsored scientific exchange group led by Dr. John Buckley. He was able to apply some of the Tahoe research technology to this lake.

NASA-Ames

Aerial photography and photo-interpretation services were available to the Tahoe Limnology Group through the NASA-Ames group at Moffett Field, California. The federal government has recently shown great interest in the use of remote sensing in the study of environmental problems. Cooperative studies involved the distribution of sediment plumes from the Upper Truckee River (Goldman et al. 1974), and aerial spectrophotometric determination of lake chlorophyll distribution (Weaver and Arvesen). Distribution maps derived from photos are compared with simultaneous "ground truth" measurements of physical and chemical parameters in the lake itself. The great potential for rapid and extensive monitoring of lake conditions by aerial photography has required detailed calibration by "water truth" studies in the lake (see Section VII).

Tahoe Research Group (NSF-RANN)

This multidisciplinary research project has continued several aspects of the EPA-supported work and involves integrated studies ranging from nutrient release and erodability of soils in the basin to the attitudes and policy preferences of decision makers. The research has as its principal objective the identification and measurement of the impacts--physical, biological, and social--of commercial and recreational development of the Lake Tahoe basin. One faction of this research involves the correlation of water quality data from the limnological research with terrestrial ecosystem disturbances in order to develop causal relationships between terrestrial ecosystem disturbance and water quality in Lake Tahoe. The RANN study is striving to quantify the soil losses which contribute to the pollution of Lake Tahoe. The primary productivity data, four years of which were developed with EPA support, has already provided important information about the sources, rates, and types of nutrient and sediment inflows. This has made it possible to analyze and determine the sources of increased productivity in the Tahoe basin.

State Division of Parks and Recreation

The University of California, Davis, agreed to provide assistance to the Division of Parks and Recreation in establishing a public information center at Lake Tahoe. This center has not yet been established, but should eventually provide visual aids for conservation education including scientific exhibits and photographic displays of the physical and biological resources of the basin. Initial arrangements for this cooperative effort were made through William Penn Mott, Director of the Division. A 16 mm color conservation and science education movie of Tahoe has been filmed and is in the final stages of preparation which should be of great value in public education.

Scripps Institute of Oceanography

Dr. O. Holm-Hansen and his associates of Scripps Institute of Oceanography at La Jolla have utilized our research facilities on several occasions for their collection of ATP, DNA, chlorophyll, and nutrient samples. Our cooperative studies have covered various phases of biochemical and physical limnology for comparisons with their oceanographic data. Lake Tahoe is now recognized by the Scripps oceanographers as an excellent freshwater body for use in comparisons with oceanographic findings. A joint paper on the chemical and biological characteristics of a Lake Tahoe water column (Holm-Hansen et al. unpublished) is being completed. Mr. Dale Kiefer, Dr. Tom Berman and Dr. O. Holm-Hansen also undertook a study of the areal and vertical variation of chlorophyll using fluorometric procedures. Initial results were interesting since an unsuspected layer of chlorophyll was discovered between 300 and 350 m (Kiefer et al. 1972). The importance and structure of this layer remains unknown, but will be the subject of further study.

Mr. Peter Hacker of S.I.O. has utilized our research vessel and men on several occasions to gain information for part of his doctoral dissertation on the changes in micro-structure of thermal stratification with depth. Using a boomerang recording thermistor unit, he began the investigation of the extent of deep water mixing in Lake Tahoe (Hacker 1973). He did detailed conductivity analyses and aided in the calibration and interpretation of reversing thermometer data (see Section IV).

Dr. E. Goldberg from S.I.O. has obtained several samples from sediments located in deep (450 m) waters. These cores have been analyzed for isotopes of lead to detect increases of this element in the sediments from increased human activity (automobile exhaust) in the Tahoe basin (Koide, Bruland, and Goldberg 1972).

Dr. Ray Smith of Dr. John Tyler's group at S.I.O. utilized our equipment to supplement his determinations of the spectral quality of Lake Tahoe water. Use of an alpha meter and spectroradiometer produced data on percent light transmission and changing spectral qualities of the water with increasing depth (Smith, Tyler, and Goldman 1973) (see

Section IV).

University of Southern California

A separate grant proposal involving studies of sediment redistribution within Lake Tahoe has been submitted to NSF-RANN by Dr. Donn Gorsline of U.S.C. This work will require use of the University of California research vessel and will be coordinated with stream and lake erosional input studies by the Tahoe Limnology Group. A knowledge of sediment movement after deposition in the lake is of particular importance with respect to patterns of eutrophication that may result primarily from nutrient release from sediments by heterotrophs. Greater understanding of lake currents and factors affecting changes in sandy beaches of great recreational value will also result from these studies.

Geology of the Tahoe Basin

The almost complete lack of information concerning the geology below the lake surface of Tahoe prompted this investigation. Previous work has resulted in the construction of a bathymetric map of Lake Tahoe from a precision depth recorder survey (Goldman and Court 1968, Hyne et al. 1972). See Section IV for details of this work. Norman J. Hyne (Dept. of Geol. Sci., Univ. of Tulsa), Paul Chelminski (Bolt Associates, Norwalk, Connecticut), James E. Court (Dept. of Geology, City College of San Francisco), Donn S. Gorsline (Dept. of Geol. Sciences, Univ. of Southern California), and Charles R. Goldman (Div. of Environmental Studies, U.C. Davis) have all contributed to this work.

University of California, Davis

A proposal for the study of Lake Tahoe's heat budget by Drs. Thomas Powell, Leonard Myrup, and Peter Richerson has been funded by NSF.

These studies propose to describe the relation between a lake's changing physical conditions and subsequent ecological effects. Such research will include considerations of local atmospheric conditions, lake currents, and wave motions among other environmental factors. The sophisticated electronic monitoring equipment necessary for the determination of the Tahoe heat budget will be installed in our new laboratory (shortly to be constructed). In addition, the use of our SCUBA equipment, divers, boats, and lab personnel will be required in the installation, maintenance, and manipulation of the field sensors and equipment utilized in their studies.

Lake Tahoe Area Council (LTAC) and Lake Tahoe Environmental Education Consortium (LTEEC).

A project involving the eutrophication of streams and surface waters of Lake Tahoe has been conducted for several years under the direction of Dr. P. H. McGauhey of U.C. Berkeley for the LTAC. They have independent laboratory facilities and funds, but have been assisted by Dr. Goldman in the form of lab furniture and help with sampling in the lake and planning initial phases of the research. Information dissemination of EPA-sponsored research findings are now being assisted by the LTEEC with the aid of a new, NSF funded, research coordination board.

League to Save Lake Tahoe.

The League has provided partial funds for the production of a 30 min., 16 mm color movie, now nearing completion, depicting the nature and extent of field and laboratory work at Tahoe, and the support program for data analysis in Davis. Dr. Goldman and his associates have given a number of slide talks to League meetings on the subject of Lake Tahoe and related conservation issues. Dr. Goldman is currently serving as a member of the Board of Directors. A small water use study for selected areas of the Tahoe basin was funded by the League in 1969 and a report has recently been submitted.

Tahoe Regional Planning Agency (TRPA)

Dr. Goldman and his associates have had steadily increasing interaction with the TRPA and Forest Service environmental planning at Lake Tahoe. They have served on various technical committees of TRPA, assisted in upgrading planned unit developments, and participated in TRPA public hearings on regional planning. On 17-18 July 1972 a jointly sponsored meeting on remote sensing was held at South Tahoe.

SECTION IV

PHYSICAL CHARACTERISTICS

LIGHT

Methods

Solar radiation has been recorded directly and continuously since July 1967 with a pyrheliometer (Belfort Instruments, Baltimore, Md.). The daily light curve recorded on the chart was then planimetered and the total amount of langleys available that day at the surface of the lake was computed. The instrument was calibrated with an Eppley unit.

Transparency was measured with both a Secchi disk (25.5 cm in diameter) and with a photometer. A Rigosha submarine light meter was used in 1967. In 1969 and subsequent years a submarine photometer (G.M. Mfg. Instrument Corp., Model No. 268WA310) replaced the previous instrument. The deck cell was used to correct for any changes in sky light intensity during the course of the measurements. The surface value for transmitted light was measured just below the air-water interface in order to eliminate any possible increase in intensity due to reflection and scattering of light at the surface caused by small waves. The percentage of surface light transmitted at each sampling depth was calculated from the photometer measurements. The extinction coefficient was computed from those values.

The Scripps spectroradiometer (Tyler and Smith 1966) was used to measure absolute values of spectral irradiance for a comparison of the optical properties of Tahoe and Crater Lake, Oregon (Smith, Tyler, and Goldman 1973). Principal features of the instrument include: a double Ebert monochromator to minimize stray light within the instrument, a carefully constructed and calibrated underwater collector, spectral sensitivity from 350 to 750 nm, an accurate (5-10%) and precise (±2.5%) response, a sensitivity (with 5 nm bandwidth) to energy levels down to 0.005 $\mu W \cdot cm^{-2} \cdot nm^{-1}$ (less than 0.01% of the average noon surface spectral irradiance in the blue region of the spectrum), and an absolute calibration. The submersible spectroradiometer and experimental details for spectral irradiance measurements have been discussed in detail by Tyler and Smith (1966, 1970).

Beam transmittance was measured using a 1-m pathlength transmissometer (Petzold and Austin 1968). Salient features of the instrument are: a cylindrically limited and folded beam; fixed optical alignment; temperature, fatigue, and drift stability; insensitivity to ambient light; and a means of checking calibration while the instrument is submerged. This instrument has less than a few tenths of one percent error due to forward scattered light for the work reported by Smith, Tyler, and Goldman (1973).

Results

Solar Radiation -

The amount of solar radiation received on the surface of the lake varies from a minima of a few langleys ($g\ cal \cdot cm^{-2}$) per day on dark days in the winter months to maxima above 650 langleys per day. Figure 3 shows the seasonal variation of solar radiation at Lake Tahoe in langleys per day for each single day of the year and the total amount of solar radiation that reaches Lake Tahoe each year. Deviations from the expected smooth seasonal curve of solar radiation (Fig. 4), due to the seasonal

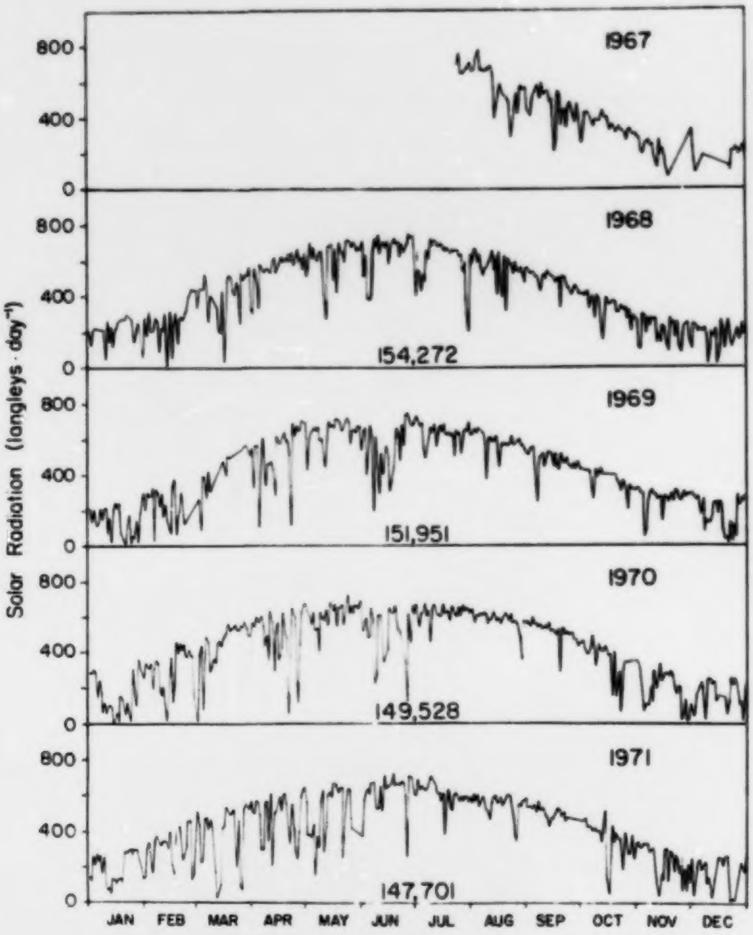

Figure 3. Daily solar radiation at Lake Tahoe from mid-1967 through 1971. The total yearly radiation in langleys is also indicated.

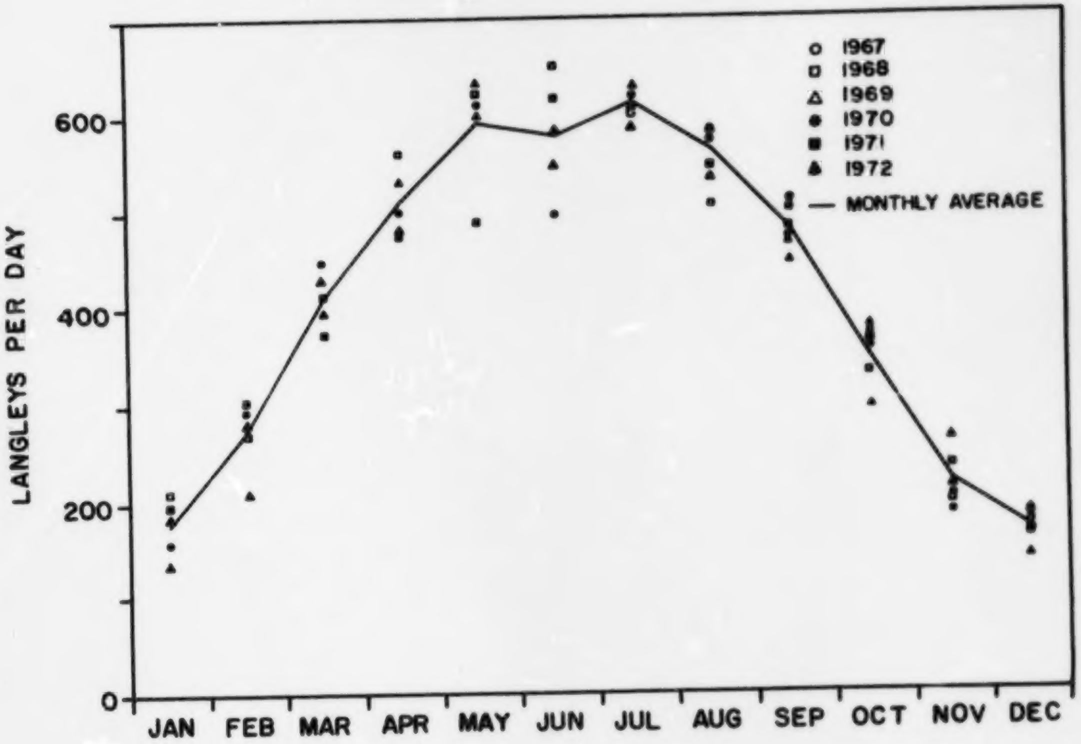

Figure 4. Seasonal solar radiation at Lake Tahoe calculated from monthly averages from mid-1967 through 1972. Each point is the average for the month.

variation of the path of the sun, reflect weather conditions at Lake Tahoe. There were a few very dark days in 1968 in the winter and summer months, with a summer low of 185 langleys on 31 July. No such very dark days were observed in mid-summer days of the following years. There were, however, half as many dark days in the winter of 1968 as in the winters of the following years. For the first three months of 1968 there were 14 days with less than 200 langleys of incoming solar radiation as compared to 31 days, 30 days, and 27 days for 1969, 1970, and 1971, respectively. In 1969, the winter minimum was observed on 21 January with 2.5 langleys for the day. The summer of 1969 shows less light fluctuation from very cloudy days than the other three years. The minimum in the winter of 1970 was reached on 14 January with 7.5 langleys for the day. There was more total solar radiation for the first three months of that year than for any of the other years. In 1971 the minimum winter light recorded was 45 langleys on 13 January. The total and mean monthly insolation and the total amount of solar radiation that reaches the surface of the lake each year is given in Table 1. It shows a steady decline from one year to the next in the total amount of solar radiation that reaches the surface of Lake Tahoe.

The maximum solar radiation recorded on any one day for each of the four years also shows a slow but steady decline in solar radiation since 1968. Each of these days was a clear day, without cloud cover for the period of time immediately preceding or following the 21st of June. Unfortunately this decline is roughly within the experimental error of the instrument. If it is real, it may reflect an important increase in air pollution or cloud cover.

Transparency -

First measurements of Secchi disk transparency at Lake Tahoe were recorded by Le Conte in 1883. Since then Lake Tahoe has had the reputation of being among the clearest lakes of the world. Although many Secchi

TABLE 1. INCIDENT SOLAR RADIATION AT LAKE TAHOE, 1967-1972

MEAN MONTHLY LANGLEYS PER DAY

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN YEARLY LY/DAY
1967	---	---	---	---	---	---	---	581	474	361	207	178	
1968	210	269	410	558	621	650	604	556	481	332	202	169	423
1969	138	210	430	531	637	548	627	581	473	368	260	178	416
1970	157	296	445	498	611	496	616	572	511	354	185	165	410
1971	191	300	373	478	488	617	607	547	500	357	230	164	405
1972	184	276	398	483	597	580	596	538	446	296	212	141	397
MONTHLY AVERAGE	176	270	411	510	591	578	610	562	481	345	216	166	

TOTAL LANGLEYS PER MONTH

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL PER YEAR
1967	---	---	---	---	---	---	---	18,005	14,220	11,185	6,221	5,506	---
1968	6,510	7,545	12,712	16,725	19,250	19.510	18,715	17,230	14,440	10,310	6,070	5,255	154,272
1969	4,270	5,872	13,323	15,920	19,755	16,425	19,435	18,010	14,201	11,420	7,785	5,535	151,951
1970	4,875	8,300	13,805	14,940	18,930	14,865	19,095	17,730	15,335	10,975	5,550	5,128	149,528
1971	5,940	8,410	11,565	14,341	15,130	18,500	18,805	16,960	15,010	11,070	6,898	5,072	147,701
1972	5,690	7,998	12,340	14,500	18,500	17,410	18,475	16,665	13,365	9,175	6,350	4,370	144,838

disk records have been taken between 1959 and 1963 (Goldman and Carter 1965), Secchi disk readings have been taken more frequently since 1967 and on an all-year round basis, approximately every week in summer and every two weeks in winter. Seasonal variation of Secchi disk transparencies at the index station shows typically higher transparencies in the early part of the year, lower in summer, and higher again in the last part of the year. Most of the highest values occur early in the year. For the half year of data recorded in 1967, the lowest Secchi disk transparency recorded was 12 m on 25 August and the highest value of 31 m was recorded on 1 November. On 8 February 1968 the highest value that has ever been recorded at Lake Tahoe was a 43.25 reading. Other locations in the lake during the same time period were also giving measurements of Secchi disk transparency of over 40 m. On 31 July of the same year, the lowest value for the year was recorded as 16.5 m.

On 15 March 1969, another high reading (40.4 m) was taken with the Secchi disk at our index station. This was the maximum for the year, and a value of 15.5 m on 20 June was the minimum. In 1970 and 1971 the pattern of seasonal variation of the Secchi disk measurements was somewhat altered from the previous one. In 1970 a very low value of 17.0 m was recorded on 19 January. This was the minimum for that year and the maximum of 35 m was measured on 5 May. In 1971, the maximum of 35.25 m was recorded on 12 February, a low of 20.5 m was read on 1 June, but the minimum for the year (19 m) was measured on 29 November. Mean monthly Secchi disk transparency values are shown in Figure 5 . These values have been obtained by planimetering by month the area under the curve of Secchi depth variation and dividing by the number of days in that month. The greatest mean monthly Secchi disk recording was 37.4 m for February 1968, the lowest was 19.8 m for August 1967, followed by 20.2 m for November 1971. The average daily Secchi disk transparency reading, based on a whole year of data, was found to be 29.3 m for 1968, 27.8 m for 1969, 29.0 m for 1970, and 27.6 m for 1971. It is doubtful that

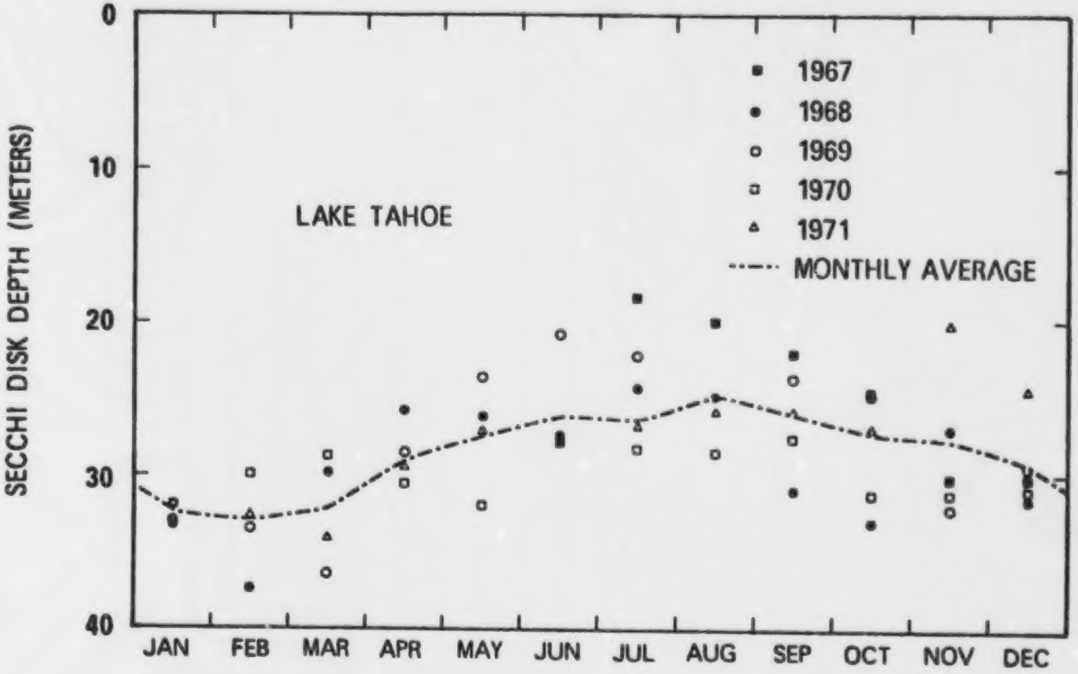

Figure 5. Seasonal Secchi disk transparency at the index station of Lake Tahoe calculated from monthly averages from mid-1967 through 1971. Each point is the average for the month.

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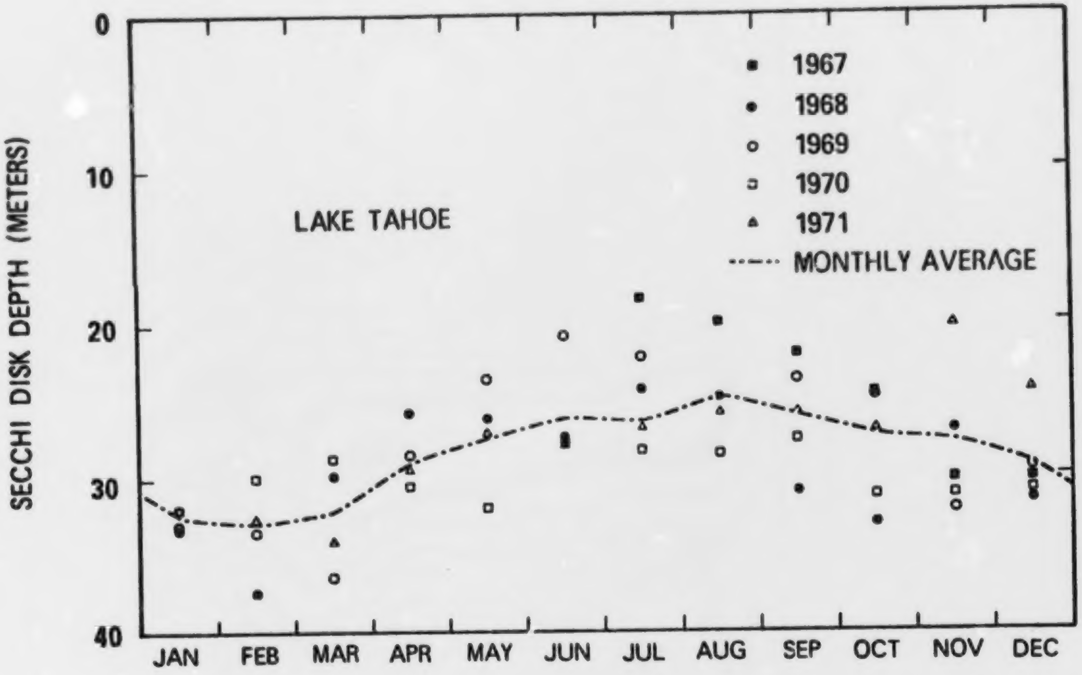


Figure 5. Seasonal Secchi disk transparency at the index station of Lake Tahoe calculated from monthly averages from mid-1967 through 1971. Each point is the average for the month.

this represents a significant change in the transparency of Lake Tahoe over the four years in question.

Measurements of transparency obtained with the submarine photometer are given in Tables 2-4. These are expressed as the percentage of surface light transmitted at each sampling depth and are shown together with the amount of cloud cover for each of our sampling days in 1969, 1970, and 1971. A change in scale for photometer readings at low light intensity is reflected by an increase in the number of decimal places given in the results.

To move from these conventional measures of transparency to a higher order of precision required the use of specialized equipment from the visibility laboratory at the Scripps Institution of Oceanography. The Scripps' submersible spectroradiometer was used for a comparative study of the optical properties of Lake Tahoe and Crater Lake, Oregon. Although summarized below, this study appears in detail in Smith, Tyler, and Goldman (1973). The remarkable clarity of the water, particularly in the 400 to 550 nm range, is evident in Figure 6.

Color -

Of particular importance at Lake Tahoe is the color of the lake water. Descriptions of the beauty of the "cobalt blue" waters of Tahoe are legendary, yet we have no way of knowing whether or to what extent Lake Tahoe has changed its color since the early descriptions of its color and beauty. It is now possible, however, with a knowledge of the spectral composition of the radiant energy upwelling from lake waters, to make an objective evaluation of the color attributed to lake waters in terms of the C.I.E. chromaticity coordinates. A detailed discussion of color and its quantitative description is given in The Science of Color (Optical Society of America 1953). An evaluation of color in terms of the C.I.E. chromaticity coordinates requires: (1) A source of

TABLE 2. PERCENT LIGHT TRANSMISSION AT THE INDEX STATION OF LAKE TAHOE, 1969.

DATE	16 JAN	1 FEB	2 MAR	15 MAR	30 MAR	13 APR	19 APR	25 APR	9 MAY	23 MAY	7 JUN	20 JUN	1 JUL
% CLOUD COVER	50-100%	100%	75-100%	0%	40%	0%	0%	0%	0%	0%	5%	15%	0%
DEPTH (M)													
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	54.0	59.5	75.3	68.2	63.6	82.6	78.3	91.2	92.5	87.8	70.4	80.0	76.0
5	54.0	54.8	64.7	54.5	52.7	86.3	60.0	73.6	78.8	75.6	52.4	67.0	47.0
10	45.6	40.5	47.0	44.3	40.0	50.0	46.6	54.9	61.2	51.2	32.0	52.2	33.6
15	32.6	32.4	40.0	36.4	29.1	33.4	35.0	30.6	52.5	28.0	20.4	28.7	18.5
20	22.6	25.5	32.9	26.1	25.4	29.1	27.2	28.6	43.0	21.0	11.2	28.7	12.4
30	13.6	15.5	17.5	16.1	15.1	14.5	17.4	13.4	12.1	8.9	6.3	7.7	5.3
40	5.8	10.2	11.3	9.8	8.4	7.9	9.9	6.5	7.9	3.6	2.7	2.7	3.5
50	3.2	6.4	7.1	5.7	4.6	4.3	5.2	3.3	4.1	2.4	1.3	2.1	2.3
60	2.1	5.0	3.5	4.3	2.7	2.0	2.7	2.2	2.0	.93	.75	1.2	.73
75	.96	2.7	2.2	1.5	1.4	.78	1.2	.87	.74	.43	.26	.55	.47
90	.48	1.5	1.2	.70	.65	.37	.40	.33	.28	.14	.11	.30	.17
105	.37	.78	.56	.31	.27	.10	.18	.13	.13	.052	.042	.11	.070

DATE	8 JUL	15 JUL	22 JUL	24 JUL	30 JUL	5 AUG	14 AUG	20 AUG	28 AUG	3 SEP	9 SEP	15 SEP	23 SEP
% CLOUD COVER	0%	0%	0%	1%	0%	0%	0%	0%	0%	2%	10%	5%	0%
DEPTH (M)													
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	78.3	85.0	78.9	71.6	72.5	80.4	80.4	72.3	85.8	15.9	60.0	63.2	75.6
5	59.8	72.5	60.0	55.7	52.0	62.0	63.7	48.4	56.7	14.5	53.6	55.6	61.0
10	39.1	50.0	41.0	36.4	37.2	41.3	40.0	36.1	43.8	14.3	39.3	44.2	54.9
15	27.8	36.2	29.2	23.9	27.4	30.4	24.5	27.5	33.4	13.1	29.0	38.9	42.7
20	18.9	17.2	18.8	17.0	20.0	22.8	17.0	20.5	24.7	11.6	21.2	27.4	—
30	10.1	7.1	9.8	9.6	10.5	12.8	10.6	11.6	13.5	8.2	10.6	9.5	—
40	5.7	4.0	4.4	5.0	5.9	7.5	6.3	6.4	7.5	5.5	5.5	4.4	—
50	3.8	2.6	3.5	3.1	3.1	4.3	3.5	3.4	4.2	3.2	3.0	3.2	—
60	2.5	1.2	1.5	1.8	1.3	2.3	2.1	2.2	2.9	1.3	1.6	1.4	—
75	.58	.46	.46	.75	.72	.94	.93	.78	1.4	.88	.65	.55	—
90	.40	.34	.25	.33	.20	.43	.37	.35	.67	.42	.31	.32	—
105	.14	.09	.11	.15	.15	.18	.18	—	.30	.21	.15	.12	—

TABLE 3. PERCENT LIGHT TRANSMISSION AT THE INDEX STATION OF LAKE TAHOE, 1970.

Date	30 Jan	10 Feb	23 Feb	28 Feb	10 Mar	15 Apr	2 May	13 May	25 May	4 Jun	16 Jun	1 Jul	7 Jul	14 Jul	20 Jul
% Cloud Cover	40-60%	100%	0%	100%	70%	90%	0%	60%	0%	10%	50%	0%	0%	0%	50%
Depth (m)															
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	59.3	71.1	96.3	100.0	92.5	80.9	76.4	74.1	75.0	76.8	71.1	100.0	67.2	74.4	96.6
5	51.8	66.7	88.9	100.0	87.5	64.0	58.3	59.8	61.4	60.0	48.2	97.3	55.2	59.0	77.6
10	----	60.4	89.6	85.7	75.0	47.2	47.2	50.6	47.7	40.0	38.6	78.4	50.7	51.3	58.6
15	52.1	48.0	81.5	64.3	67.5	37.1	38.9	35.7	39.8	29.5	36.1	62.2	35.2	43.6	50.0
20	42.8	36.9	56.4	32.7	40.0	31.5	33.0	30.4	34.1	24.2	31.3	42.7	30.1	35.9	41.4
30	36.0	20.4	47.0	9.4	25.0	22.5	27.9	22.0	21.4	15.7	20.2	36.8	22.1	22.2	24.2
40	14.0	11.1	31.3	6.7	15.0	11.6	16.0	14.5	13.3	9.0	14.3	25.1	24.6	14.6	16.9
50	10.5	2.7	18.8	3.7	9.2	7.4	11.2	8.2	7.4	5.4	8.7	11.2	8.6	8.8	11.4
60	1.8	1.4	5.0	2.1	1.8	4.5	6.7	5.6	4.3	3.4	5.2	9.4	5.5	6.1	8.4
75	1.3	.76	2.5	1.3	1.5	.90	3.5	2.8	.82	.58	2.8	1.9	1.1	3.5	4.6
90	.57	.56	1.6	70	.97	.53	.64	.40	.36	.28	.43	.66	.52	.34	.71
105	.29	.27	.85	.32	.58	.25	.35	.36	.28	.20	.27	[illegible]	.36	.27	.44
125	----	----	----	----	----	----	.17	.18	.11	.080	.12	[illegible]	.16	.12	.19
150	----	----	----	----	----	----	----	----	.039	.028	.047	.10	.058	.017	.071

Date	24 Jul	31 Jul	11 Aug	17 Aug	24 Aug	2 Sep	8 Sep	17 Sep	23 Sep	2 Oct	14 Oct	10 Nov	6 Dec	22 Dec
% Cloud Cover	0%	2%	0%	60%	0%	0%	0%	0%	0%	0%	0%	20%	0%	5%
Depth (m)														
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	80.0	73.5	72.0	65.8	76.6	79.0	75.6	66.0	70.2	76.4	76.6	68.7	54.4	78.9
5	69.2	[illegible]	60.3	57.5	55.8	67.7	61.3	52.6	56.1	65.4	[illegible]	54.2	45.3	63.2
10	53.8	44.1	45.6	46.2	53.2	50.0	45.2	46.3	36.6	46.1	42.8	55.8	47.6	58.4
15	46.2	36.5	36.8	35.6	39.0	38.7	[illegible]	40.4	37.5	40.0	44.6	42.7	33.8	46.3
20	38.5	36.3	33.5	36.1	29.9	32.2	35.4	32.4	28.1	40.0	38.4	32.3	26.0	33.7
30	23.6	21.9	21.6	24.6	27.9	26.7	24.0	20.9	15.4	25.4	24.6	18.6	13.1	18.9
40	15.2	14.0	14.1	15.8	18.4	18.5	15.0	11.3	8.8	15.8	15.0	10.6	7.3	10.3
50	10.8	6.5	8.4	10.2	12.2	11.6	9.4	7.4	5.4	8.2	6.4	6.2	4.0	5.0
60	1.2	5.4	5.9	6.5	7.8	7.2	5.6	1.6	2.6	5.4	5.7	1.4	.91	1.3
75	.58	1.0	.96	3.3	1.6	3.4	1.2	.75	.50	2.7	1.0	.55	.40	.63
90	.32	.47	.39	.65	.75	----	.21	.32	.40	.40	.41	.46	.34	.54
105	.19	.29	.36	.52	.32	.40	.27	.26	.10	.33	.20	.26	.16	.32
125	.10	.12	.13	.21	.25	.16	[illegible]	[illegible]	.074	.13	.12	.082	.053	.14
150	----	.034	.045	.080	.072	.050	.048	.036	.005	.044	.041	.018	.016	.059

TABLE 4. PERCENT LIGHT TRANSMISSION AT THE INDEX STATION OF LAKE TAHOE. 1971.

Date	8 Jan	21 Jan	3 Feb	12 Feb	22 Feb	7 Mar	17 Mar	2 Apr	13 Apr	23 Apr	5 May	19 May	1 Jun	14 Jun	25 Jun
% Cloud Cover	75%	0%	0%	30%	100%	80%	0%	75%	100%	5%	65%	80%	100%	0%	0%
Depth (m)															
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	71.9	72.7	74.5	75.6	100.0	71.6	76.4	60.3	64.5	64.9	77.2	98.5	63.0	69.4	67.8
5	84.0	61.4	61.7	63.5	94.8	49.1	65.4	51.7	58.1	56.8	64.4	85.4	51.1	56.4	55.4
10	66.9	50.0	46.8	46.4	85.7	39.5	58.2	44.8	60.8	44.6	42.8	77.4	53.4	45.2	41.1
15	46.2	36.4	34.0	46.1	69.7	32.1	47.3	39.6	51.7	36.5	33.8	71.5	38.9	32.2	35.7
20	34.2	35.9	27.6	34.2	51.4	29.4	40.0	40.9	42.2	28.4	26.0	53.3	27.5	25.8	28.6
30	19.3	20.9	22.3	21.8	32.0	26.6	33.1	27.6	26.0	22.4	24.1	41.7	14.5	14.0	25.9
40	9.0	12.0	11.3	12.6	17.7	18.0	21.1	19.5	16.2	14.4	14.6	15.9	8.0	7.6	15.2
50	2.3	6.5	7.0	6.6	10.8	11.0	12.0	13.6	10.1	9.2	7.2	14.7	2.0	4.4	8.2
60	1.7	1.8	3.8	1.9	6.8	5.9	8.2	8.4	6.1	5.5	3.6	8.3	1.1	2.7	4.4
75	.74	.80	.74	.87	1.5	3.1	4.5	4.3	1.5	2.8	.35	2.4	.53	.48	.71
90	.79	.40	.34	.52	.88	.63	.49	2.2	.77	.58	.51	1.9	.44	.31	.25
105	.36	.42	.34	.46	.46	.31	.36	.52	.47	.32	.25	1.0	.22	.15	.22
125	.12	.18	.13	.22	.20	.25	.41	.34	.40	.22	.088	.48	.090	.080	.082
150	.026	.005	.047	.083	.079	.11	.16	.12	.15	.13	.024	.13	.051	.011	.028

Date	1 Jul	8 Jul	14 Jul	22 Jul	3 Aug	11 Aug	17 Aug	24 Aug	2 Sep	9 Sep	9 Nov	24 Nov	6 Dec	16 Dec
% Cloud Cover	0%	0%	0-20%	5%	60%	5%	0%	80%	85%	10%	80%	40-80%	75-90%	0-5%
Depth (m)														
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	66.7	69.1	64.3	70.7	71.2	70.9	61.2	51.2	73.7	70.9	48.3	67.4	63.4	68.6
5	56.7	58.2	46.4	55.2	59.1	60.0	47.4	52.5	63.2	68.4	37.9	56.7	46.5	59.0
10	46.0	45.4	35.7	41.4	45.4	45.4	42.8	42.8	44.7	55.3	20.7	38.0	30.9	41.0
15	40.0	36.4	38.8	31.0	36.4	40.0	43.5	33.8	36.7	44.7	17.2	25.6	20.3	20.6
20	33.3	37.8	31.4	25.9	33.3	29.1	34.8	27.9	37.2	36.8	46.5	22.4	11.5	13.7
30	23.3	28.7	20.4	21.7	22.7	23.8	22.1	20.4	22.9	26.0	19.0	8.3	5.5	7.4
40	14.0	14.5	12.	13.1	16.2	13.6	15.2	10.5	15.6	16.3	2.7	4.9	2.8	4.2
50	7.8	8.4	7.5	6.7	10.6	7.6	8.5	6.2	9.8	9.5	—	—	—	—
60	4.5	4.9	3.8	3.6	4.2	4.0	5.0	3.7	5.6	5.5	—	—	—	—
75	2.0	2.5	.58	.60	.70	1.6	.85	.49	2.1	2.6	—	—	—	—
90	.42	.45	.41	.21	.33	.42	.36	.38	.37	.46	—	—	—	—
105	.19	.22	.18	.19	.28	.19	.26	.16	.23	.23	—	—	—	—
125	.071	.084	.11	.069	.099	.063	.10	.052	.064	—	—	—	—	—
150	.026	.033	.027	.021	.032	.023	.036	.018	.020	—	—	—	—	—

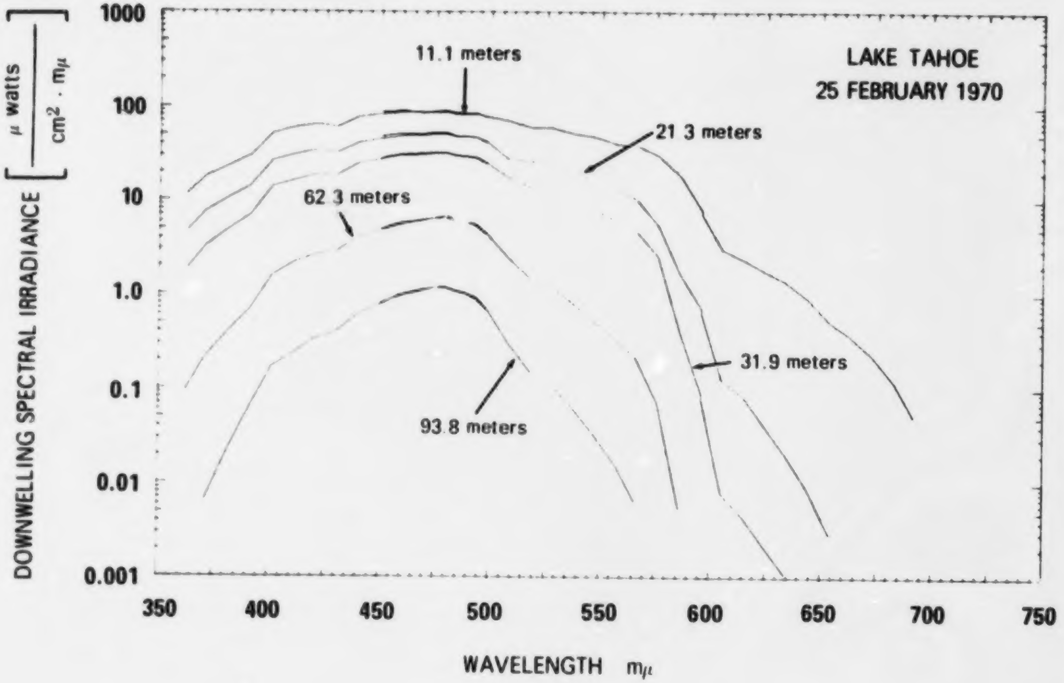


Figure 6. Downwelling spectral irradiance of Lake Tahoe. The elevation of the sun was between 40° and 42°. Data taken 25 February 1970 at the mid-lake station under clear, sunny skies and a calm water surface.

illumination, which defines the achromatic point on the chromaticity diagram. We have chosen the C.I.E. coordinate system and standard source C, an approximate representation of average daylight, which matches closely our experimental conditions. (2) An appraiser, the human observer. We have chosen luminosity data for the 1931 C.I.E. standard observer (Judd 1933). (3) An object which modifies the incident illumination by selective reflection and absorption. We shall evaluate how the waters of Crater Lake and Lake Tahoe modify and reflect the incident illumination. It is this modified and reflected light which, upon reaching the observer's eyes, constitutes the color attributed to the lake.

Using the up- and downwelling spectral irradiance data, Smith, Tyler, and Goldman (1973) have calculated the tristimulus values of this radiant energy for each depth (Optical Society of America 1953). These tristimulus values, when plotted on the C.I.E. chromaticity diagram (Fig. 7), give the numerical specification of the colors, at different depths, of the up- and downwelling illuminance of the lake waters. The loci of the color specification objectively and graphically show how the selective absorption and scattering of the indident radiant energy, with increasing depth, alter the water color. The color seen by an external observer would be closely approximated by the color calculated for the near surface upwelling irradiance.

The principal value of the tristimulus values shown in Figure 7 is that they provide an analytical tool for the objective comparison of lake color. Two lakes cannot be juxtaposed for direct visual comparison nor can a direct visual comparison be made for a single lake as its color changes with time. However, the tristimulus values of different natural waters can be compared and the changes for a single lake can be monitored over a period of time.

Because of color constancy, the aesthetic pollution (the degradation of

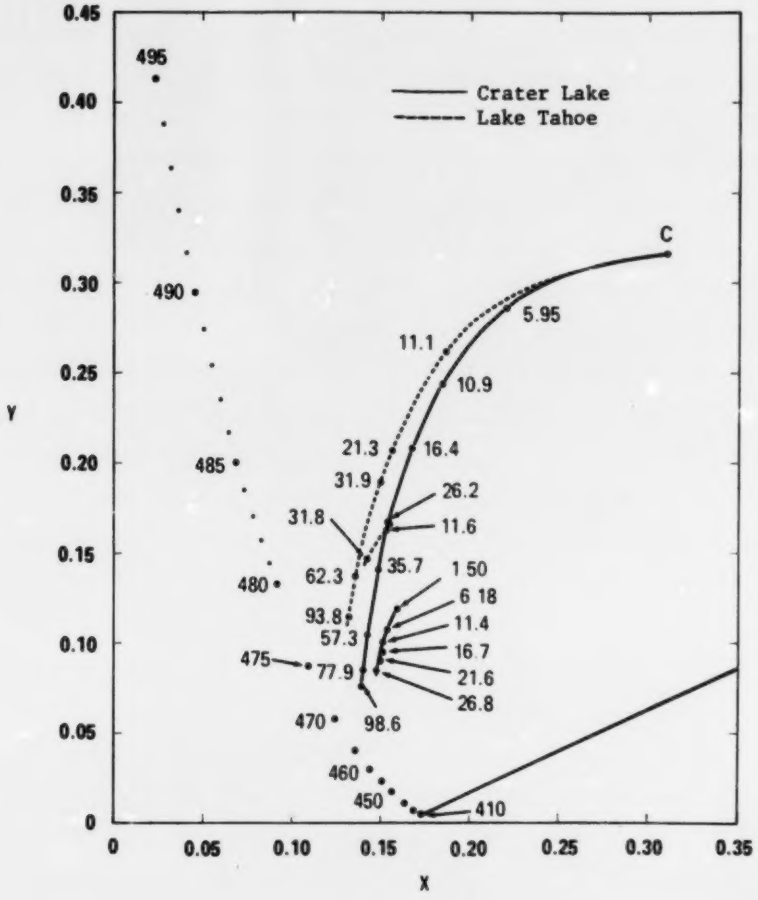


Figure 7. Tristimulus values of the upwelling (long, curved lines) and downwelling (short lines) spectral irradiance of Lake Tahoe and Crater Lake, labeled with the corresponding depth in meters. A portion of the C.I.E. chromaticity diagram (Optical Society America 1953) is also shown, with the loci of spectrally pure wavelengths represented by the dots labeled from 410 to 495 nm, based on standard source C as the achromatic stimulus.

the natural appearance) in Lake Tahoe waters may be so gradual that it could go unrecognized for some time. However, color constancy can be greatly reduced by critical, analytical scrutiny. If a means is available to make a direct comparison of change in color, the observer is likely to be startled by the amount of change he inadvertently tolerated. One technique for making such a comparison (suggested by R. W. Austin, personal communication) is to use the tristimulus values of the reflected light from the lake waters to specify the reflected color in terms of the Munsell system of color standards (Newhall, Nickerson, and Judd 1943; Optical Society of America 1953). Each Munsell color standard is labeled with a notation indicating its hue (H), value (V), and chroma (C), in the form HV/C. In the Munsell color system, the hue notation of a color indicates its relation to the spectral colors, the value notation indicates its lightness, and the chroma indicates the saturation or purity of the color (Munsell Color Co. 1967).

Table 5 gives the tristimulus values for the up- and downwelling spectral irradiance of Lake Tahoe for the depths where the irradiance measurements were made. In addition, the dominant wavelength, purity, and Munsell notation for each set of tristimulus values are given. With this information, it is possible to objectively compare the differences in color between two lakes and to see precisely how the appearance of color changes as a function of depth in either lake. More important, the data in Table 5 provide a basis for an objective evaluation of possible future changes in appearance of Lake Tahoe.

It should also be noted that sunlight filtered through a layer of smog would give a very different achromatic point. Since the appearance of smog is increasingly frequent at South Tahoe, we must unhappily point out that the appearance of the lake waters can be affected not only by the pollution of the water itself, but also by the pollution of the air above those waters. In future measurements, it may be necessary to

TABLE 5. TRISTIMULUS CHROMATICITY COORDINATES (X,Y,Z), DOMINANT WAVELENGTH (λ_d), EXCITATION PURITY, AND MUNSELL NOTATION OF THE SPECTRAL IRRADIANCE AT VARIOUS DEPTHS FOR LAKE TAHOE.

LAKE TAHOE 25 FEB 1970	DEPTH (METERS)	X	Y	Z	λ_d (mμ)	PURITY (%)	H V/C
DOWNWELLING	11.1	0.186	0.262	0.552	485.5	50.8	
	21.3	0.156	0.207	0.637	481.9	67.8	
	31.9	0.150	0.189	0.661	480.7	72.5	
	62.3	0.135	0.137	0.728	477.1	84.1	
	93.8	0.132	0.113	0.755	475.2	88.5	
UPWELLING	11.6	0.153	0.163	0.684	472.3	74.6	1.0PB 1.3/6.2
	31.8	0.142	0.146	0.712	472.8	79.9	1.5PB 1.3/7.1

select clear, well ventilated days to accurately reproduce results of light-related measurements.

TEMPERATURE

Methods

Vertical profiles of water temperature were obtained at the index station on every sampling date as well as with collections from other areas in Lake Tahoe. A bathythermograph (BT) was employed for all measurements through April 1970. Accuracy of the BT was determined to be ± 0.25°C. Readings were taken through a slide viewer calibrated by means of surface temperature adjustment to that measured independently by a "bucket" thermometer with 0.1°C divisions.

Because of increasing interest in the Tahoe temperature regime, measurements were taken after April 1970 with a thermistor equipped with a 100 m conductor (Martek TMS). The thermistor unit was calibrated before each series of readings, if necessary, and checked against a surface reading of the bucket thermometer. Accuracy was determined to be ± 0.1°C. All index station profiles were recorded between 1030 and 1130 hours.

Mid-lake deep water temperatures were taken with a series of reversing thermometers (KAHLSICO). At each depth, two thermometers were employed to give protected (ambient) and unprotected (depth-pressure) readings. Before tripping the reversing thermometer frames, at least a ten-minute wait was instituted to allow for thermometer equilibration. Readings were taken after all thermometers had been retrieved and allowed to come to ambient temperature. Protected thermometers with a range of -2° to +16°C in 0.05°C divisions were used in deep sampling where temperature variations were slight. In the upper 100 m of water where temperature changes were expected to exceed that range, thermometers with a -2°C to +30°C scale in 0.1° divisions were used. All unprotected thermometer scales were -2° to +30°C or +35°C in 0.1°C divisions. Recalibration of these thermometers was done by the Scripps Institution of Oceanography at La Jolla, California.

Results

Figure 8 illustrates the annual changes in isotherm configuration at the index station for the study period from mid-1967 through 1971. Temperature values at the index station are given in Appendix A. Heat storage depth profiles calculated from the index station temperature data are shown in Figures 9,10. Seasonal heat storage and temperature curves for several depths at the index station are shown in Figures 11,12. Temperature values measured in deep water, down to 400 m, are given in Table 6.

Although Lake Tahoe appears to follow similar patterns of thermal stratification and mixing from year to year, it was not possible to demonstrate a complete turnover with existing data until 1973 (Paerl et al. 1974). Detailed examination of the upper 100 m show that stratification and the depression of the 6°C isotherm from the surface to deeper depths has occurred around 20 April each of the four years covered by this report. Peak surface temperatures are usually reached in August and the lowest surface readings occur in Feburary - March. The lake mixes deeply and is nearly homothermous from the end of December to April or May with most of the temperature change limited to the upper 70-80 m (Table 6).

The irregular variations that occur from one sampling date to the next are characteristic of Tahoe (Fig. 8). It is possible that these are caused by long shore currents, a thermal bar, or upwelling of deeper cold water which cause a rise in the isotherm levels especially evident

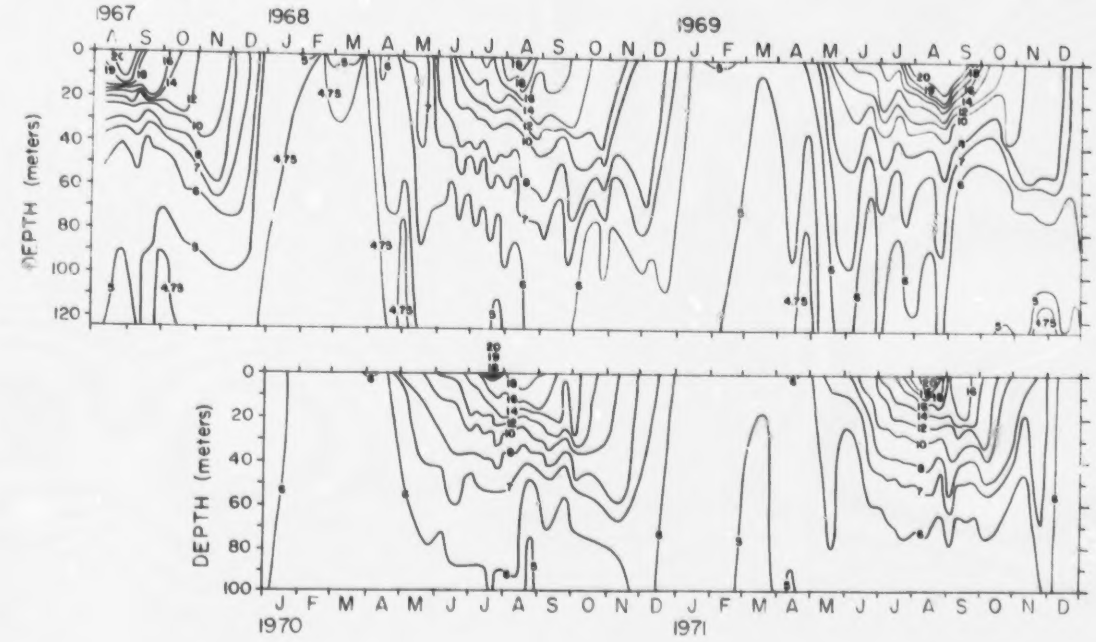


Figure 8. Isotherms (°C) for the index station of Lake Tahoe from mid-1967 through 1971.

TABLE 6. TEMPERATURE (°C) AT THE MID-LAKE STATION OF LAKE TAHOE, 1969-1971.

	1969		1970												
DEPTH M	NOV 18	DEC 17	JAN 2	JAN 20	FEB 5	FEB 25	MAR 13	APR 9	MAY 5	JUN 2	JUL 3	AUG 3	SEP 9	OCT 1	OCT 5
0	9.32	7.42	6.40	5.72	5.29	5.64	5.97	6.82	7.61	11.37	14.69	19.82	17.73	14.35	14.11
50	8.73	7.39	6.22	5.54	5.25	5.12	5.03	5.18	5.19	5.58	6.20*	6.48	6.95	7.17	----
100	4.96	5.28	6.11	5.37	4.95	4.96	4.95	5.09	4.93	5.14	5.34	5.38	5.56	5.34	5.34
200	4.64	4.66	4.67	4.73	----	4.94	4.81	4.82	4.76	4.76	4.84	4.85	----	4.85	4.84
300	----	4.62	4.62	----	----	4.67	4.65	4.64	4.66	4.66	----	4.70**	4.95	4.67	4.68
400	----	4.61	4.61	----	----	4.62	4.62	4.61	4.64	----	----	4.86**	----	4.63	4.64

				1971											
DEPTH M	OCT 16	NOV 17	DEC 30	JAN 25	FEB 10	FEB 24	MAY 10	JUN 3	JUN 30	JUL 16	AUG 4	AUG 26	SEP 14	OCT 6	DEC 8
0	13.21	9.57	5.85	5.21	5.44	5.25	6.90	9.03	13.13	18.10	20.35	19.66	18.10*	13.70*	6.60*
50	7.51	9.23	5.73	5.03	4.91	4.89	5.23	6.39	6.81	6.40	6.33	----	7.80	6.87	6.44
100	5.36	5.44	5.66	4.98	4.87	4.88	4.92	5.13	4.99	5.00	5.05	5.03	5.02	5.03	5.36
200	4.86	4.87	4.85	5.00	4.78	4.87	4.76	4.73	4.74	4.74	4.74	4.75	4.75	4.75	4.78
300	4.69	4.69	4.70	4.78	4.68	4.74	4.70	4.77	4.74	4.70	4.70	4.70	4.70	4.69	4.72
400	4.64	4.64	4.66	4.70	4.66	4.68	4.67	4.66	----	4.67	4.67	4.66	4.68	4.68	4.69

* TEMPERATURE AT THIS DEPTH MEASURED WITH A THERMISTOR.

** TEMPERATURE AT THIS DEPTH MEASURED AUG. 5, 1970.

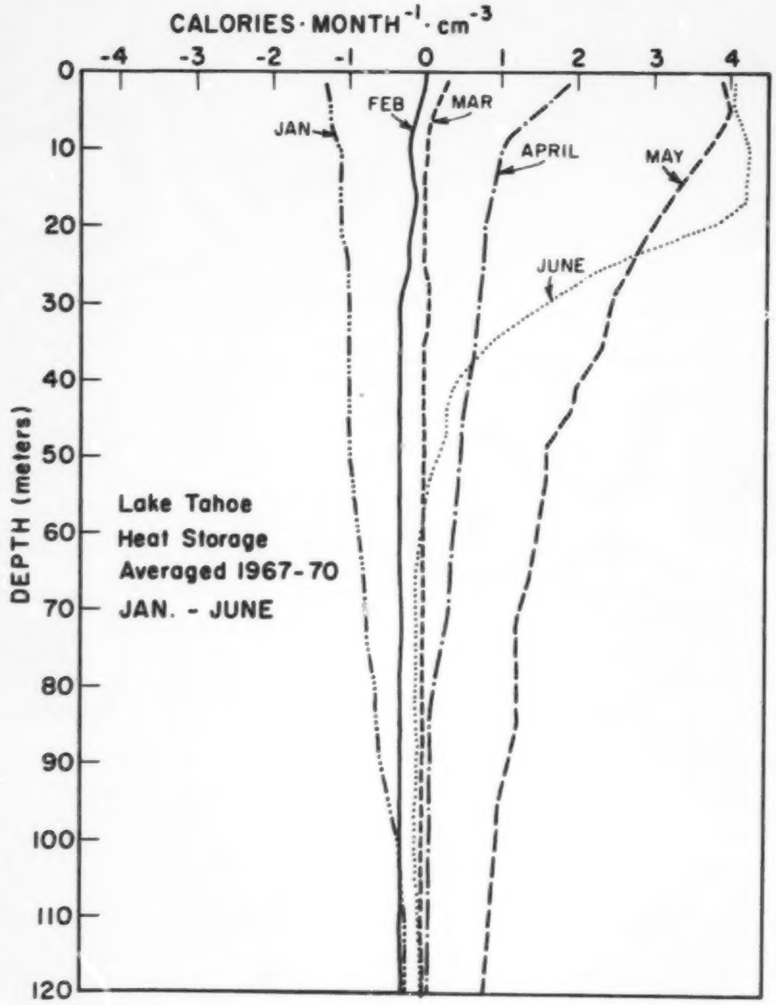


Figure 9. Monthly (January-June) heat storage-depth profiles at the index station of Lake Tahoe calculated from 1967-70 temperature data.

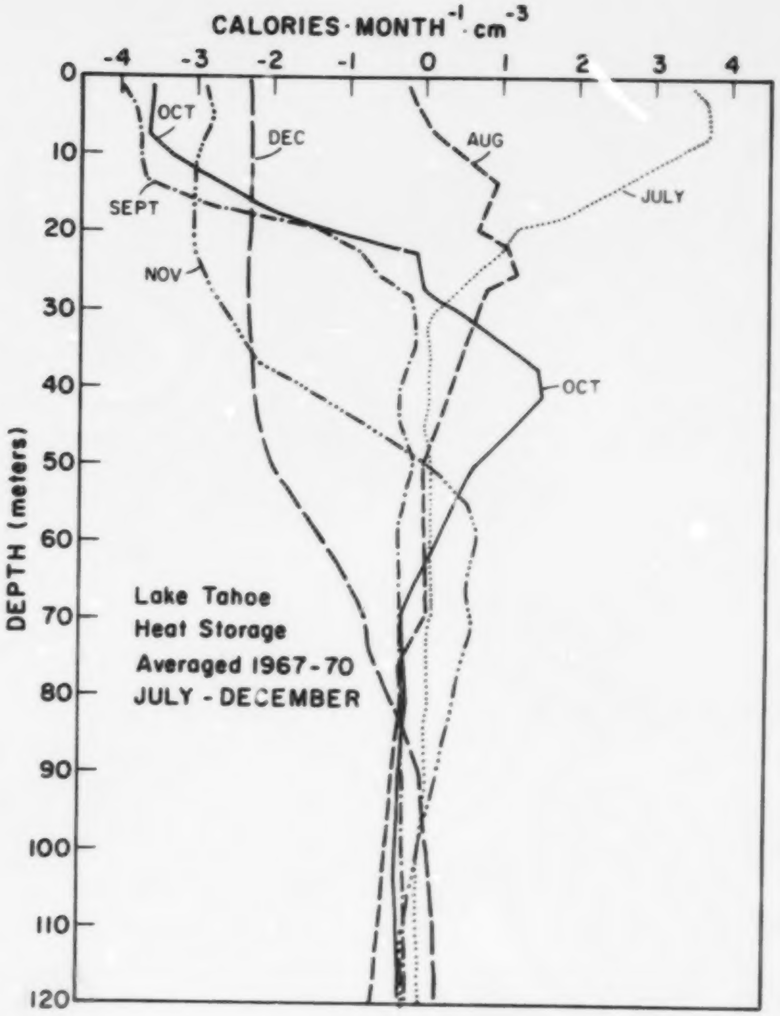


Figure 10. Monthly (July-December) heat storage-depth profiles at the index station of Lake Tahoe calculated from 1967-70 temperature data.

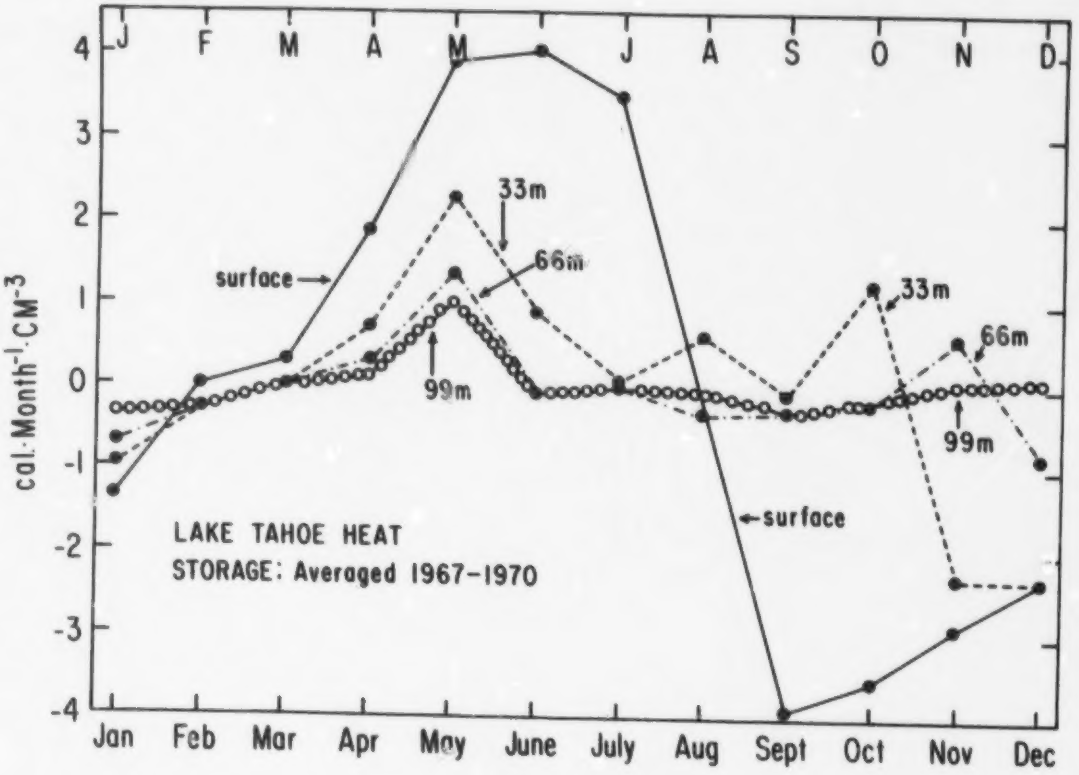


Figure 11. Seasonal heat storage at 0, 33, 66, and 99 m at the index station of Lake Tahoe calculated from 1967-70 temperature data.

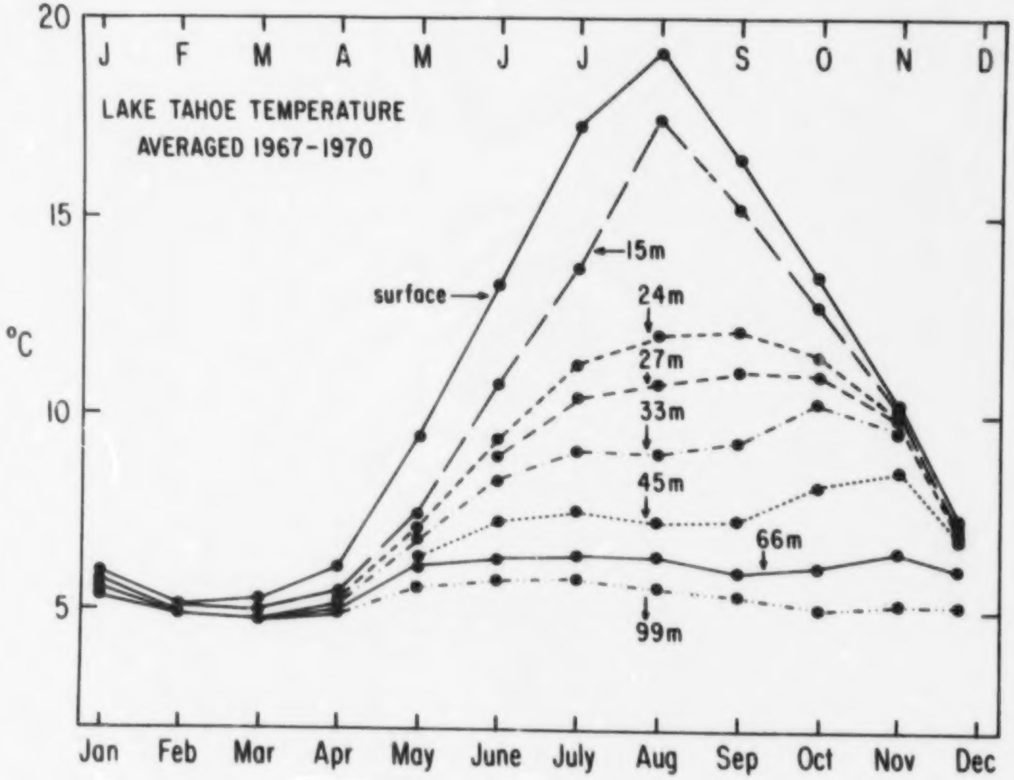


Figure 12. Seasonal temperature at 0, 15, 24, 27, 33, 45, 66, and 99 m at the index station of Lake Tahoe calculated from 1967-70 temperature data.

at greater depth. Measurements by Goldman and Bachmann (unpublished) showed a 10 m displacement of the discontinuity layer by an internal seiche. Year-to-year fluctuations in meteorology are responsible for some of the variation observed.

Well-defined stratification occurred during two years when mid-summer temperatures surpassed the 20°C mark. In 1967, stratification was most pronounced in late August and the upper 12 m of water was almost homothermous at 20-21°C. A similar situation appeared in late August of 1969 when the top 20 m was above 20°C and sharp stratification was evident below that depth. The intervening years have less well defined periods of stratification, but all, except 1968, reach surface temperatures above 20°C. The lower epilimnion temperatures present in 1968 may account, in part, for the lower level of primary production that year (Fig. 21). The influence of temperature on primary productivity is further discussed in Section VI and comparison of their vertical profiles is illustrated in Figure 20 for some days in 1969.

The significance and extent of winter mixing in Lake Tahoe cannot be fully understood from the isotherm plots of the index station. Lake Tahoe is generally considered to be a monomictic lake (mixing completely once a year), but as with other lakes is influenced by variations in the weather. The assumption that the lake undergoes complete mixing each winter was not shared by all and remained speculative until 1973. Data on deep temperature and oxygen stratification (Table 6 and Table 17), and chlorophyll and other organic and inorganic substances (Kiefer et al, 1972) indicate the total mixing of the entire water column to depths in excess of 450 m might be more complex than originally thought and possibly not completed each year.

Following the completion of the present study, the question of how completely the lake mixed was examined in more intensive fashion. Vertical profiles of NO_3-N have characteristically shown a severe depletion in the euphotic zone. Using this nitrocline it was possible for Paerl et al. (1974) to demonstrate beyond doubt that the severe winter of 1972-73 did cause a complete turnover of Lake Tahoe. The importance of this finding can scarcely be over-emphasized and leads us to believe that the lake will not completely mix during milder winters.

The principal investigator had previously noted an increase in the maximum summer surface temperature (18°C in 1965 to 20°C in 1968) coincided with increasing productivity of the surface waters and speculated that surface warming could be due to a decreasing transparency of the surface waters (Goldman, Moshiri, and Amezaga 1972). With the aid of a meterologist (Dr. L. Myrup) and a physicist (Dr. T. Powell) he began investigating the possible consequences of an alteration of the heat storage pattern within the lake.

A Decrease in the Heat Budget of Lake Tahoe, California-Nevada by Cultural Eutrophication

The hypothesis that increasing pollution of the lake will ultimately lead to cooler wintertime water and that, since the lake now approaches 4°C in winter, the surface of the lake might even freeze in some future winter has been investigated. This hypothesis has been tested by means of a physical laboratory model which reproduces, in miniature, those heat transfer processes which were selected as critical to this problem. The model generates temperature profiles and heat budgets which are similar to real-world lakes and oceans. A series of experiments have been conducted with this model in which the thermal behavior of clear and turbid water is compared. Without exception, the turbid waters become cool relative to clear waters. The "turbidity cooling" mechanism proposed here (i.e., that increased turbidity will cool systems which closely resemble natural lakes) is plausible, but further, more closely controlled experimentation on the model associated with field studies will be necessary before credible statements concerning the magnitude of the effect can be made.

The annual temperature stratification cycle of Lake Tahoe is shown in Figure 13. The lake is nearly isothermal during the winter months with a temperature approaching 4°C (the point of maximum density of water). In the summer months, the lake develops a three layer structure typical of large lakes and oceans. The upper layer (epilimnion), with nearly uniform temperature, is separated from the cool lower layer (hypolimnion) by a region characterized by a large temperature gradient (thermocline or discontinuity layer). This thermal profile is thought to be the result of interaction between absorption of solar radiation, roughly exponential with depth, and wind induced turbulence generated at the surface of the lake which acts to produce the isothermal epilimnion.

A change in transparency of the lake has been documented by aircraft photographs (Goldman et al. 1974) showing spectacular local increases of turbidity due to inflow of sediment and nutrients from areas disturbed by the many construction activities of the basin. The augmented nutrient supply has resulted in increased algal growth in the littoral zones close to the sources of pollution (Goldman, Moshiri, and Amezaga 1972). A summer increase of temperature could then be accounted for by increased absorption of solar energy by the increasingly turbid lake waters. However, the additional heat content of the surface water, gained at the expense of the deeper waters, would be more easily lost through the increased evaporation and sensible heat transfer to the atmosphere during the fall than it would be if distributed throughout the water column. The net effect of these processes, when the winter isothermal period arrives, would be a cooler lake. If a cooling trend continued for several years, the winter lake temperature would fall below that of the maximum density of water. Under these conditions, the

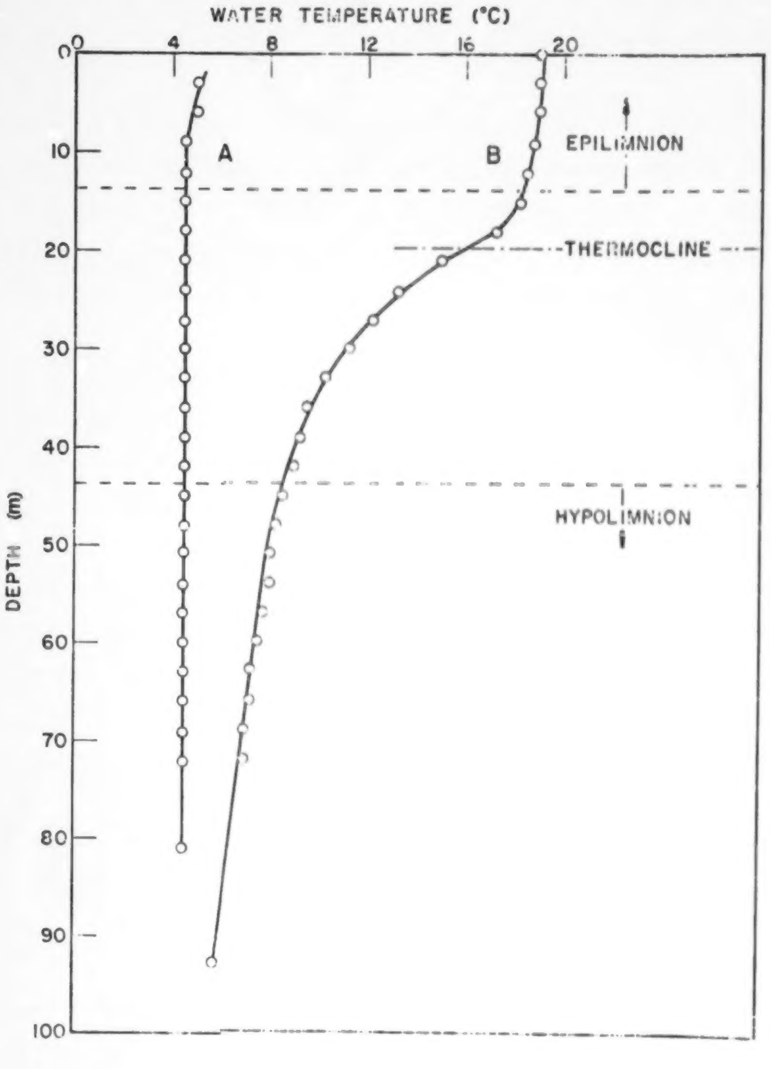


Figure 13. Annual temperature stratification cycle of Lake Tahoe, winter (A) and summer (B).

coldest water would then be buoyant and would rise to the surface, and the radiation loss to space during a clear, calm, winter night could freeze the surface waters.

Although bays occasionally freeze, there is no record of a frozen Lake Tahoe. Such a spectacular environmental modification would have profound effects on the biota at all levels of the food chain, and therefore, the possibility deserves serious study. Some of the possible ecological consequences of a freeze are the following:

1. Study of the plankton communities in Lake Tahoe (Richerson, Armstrong, and Goldman 1970) indicates that roughly 80% of the biomass of phytoplankton is produced before the summer months. A large amount of the total primary productivity of the lake occurs during the first five months of the year while its vertical curve is "unimodal" and the lake is unstratified (see Section VI). These phytoplankton organisms form the base of the food chain in the lake. A layer of ice followed by the inevitable heavy winter snows in the area would block much of the light now reaching the winter plankton. Since the resident phytoplankton require this light energy to live, it is possible that a significant change in both biomass and productivity would result from a frozen Tahoe. It is probable some species of phytoplankton best adapted to frozen alpine lakes would become dominant in place of the present three dominant species.

2. It is possible that the numbers of bacteria (detritus feeders) would increase in proportion to the phytoplankton, since these organisms are less affected by low light conditions. The place that bacteria occupy in freshwater food chains has been little studied and initial indications are that they may already play a significant role in Lake Tahoe (Paerl and Goldman 1972a).

3. Another undesirable effect is oxygen depletion, which might begin to occur at the sediment-water interface if Lake Tahoe remained ice-covered for extended periods of time in winter. This effect would make itself felt directly on such members of the Tahoe food chains as the sculpin, lake trout, and crayfish that utilize the lake bottom. These organisms are adapted to cold, oxygen-rich waters. Low oxygen conditions in winter could eventually result in reduction of their numbers.

4. Perhaps the most important effect of a frozen Tahoe would be the consequences of arresting the long winter circulation. Anaerobic conditions at the sediment-water interface could then develop causing insoluble ferric phosphate to be converted to soluble ferrous phosphate. Since the lake shows distinct iron and nitrogen limitations (Goldman 1964), a spring bloom would almost certainly result from the release of nutrients during what could amount to winter stagnation in the deep waters of the lake.

Although ecosystem dynamics are still too primitive to discriminate among these possibilities, or others for that matter, ecologists agree that any radical change at the base of the trophic structure is likely to make itself felt drastically throughout the whole food chain. Until the biota adjust to the new regime, Tahoe residents and visitors could expect a great change in the lake's organisms.

The physical model, shown schematically in Figure 14, consists of a cubic foot of water, heated from above by an ordinary 200 watt incandescent light bulb. The light is contained within a parabolic reflector which delivers 180 watts to the water surface. The surface waters are agitated by a wire grid (28 gauge wire, 18 x 14 wires$\cdot$in^{-1}) which is oscillated in the vertical direction with a stroke of 0.79 cm at a frequency of

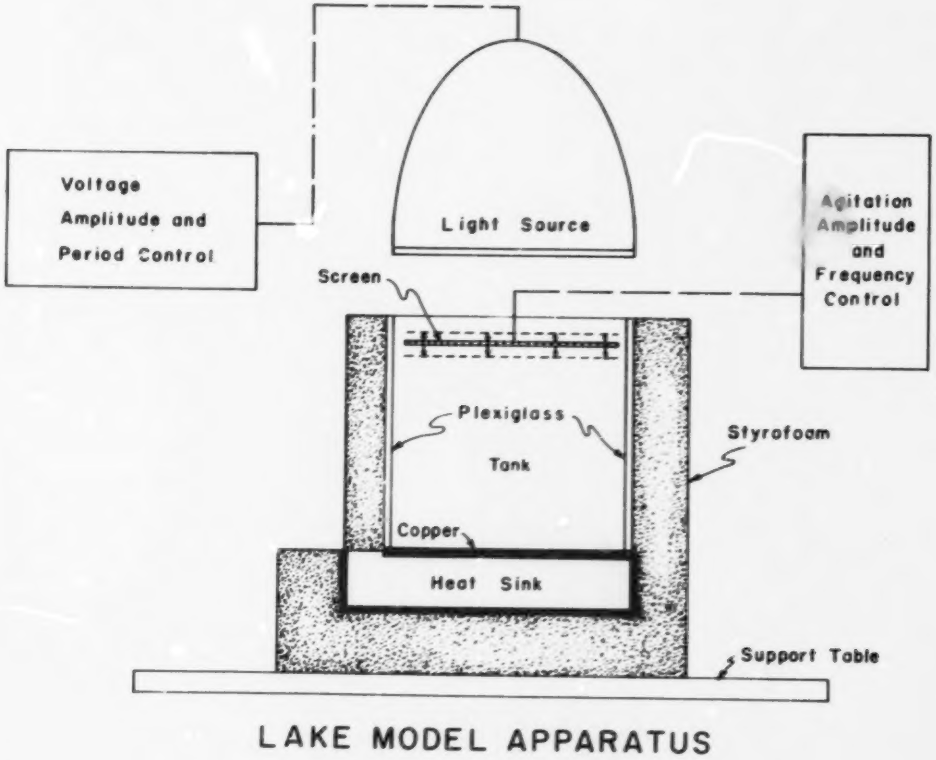

Voltage
Amplitude and
Period Control
Light Source
Agitation
Amplitude
and
Frequency
Control
Screen
Plexiglass
Tank
Styrofoam
Copper
Heat Sink
Support Table
LAKE MODEL APPARATUS

Figure 14. Schematic diagram of the Lake Tahoe physical model.

3.75 Hz. The turbidity level was controlled by adding calibrated amounts of Nigrasin dye to the water. In the experiments reported here, a dye concentration of 0.040 $g \cdot l^{-1}$ was used. The evaporation rate (latent heat loss) and rate of sensible heat transfer to the air were controlled by varying the ventilation of water surface. The physical model is related to experiments performed by Rouse and Dodu (1955) and Turner and Kraus (1967). The experiment reported here differs from its predecessors in that the thermocline is achieved by differential heating rather than by artificially setting up a fresh-over-salt water stratification.

In designing this apparatus, the following processes were chosen to model: (1) absorption of visible and infrared radiation at a rate dependent on water turbidity and distance from the surface, (2) mixing of heat by turbulence generated near the surface, and (3) removal of heat from the water surface at a rate dependent on the ventilation. No attempt has been made to achieve geometrical similarity with the Lake Tahoe basin nor to model realistic generation of turbulence by shearing motion or wave breaking. The hypothesis is that the heat budget is insensitive to the mechanism by which the surface waters are mixed.

A series of experiments were performed in which the system parameters (water turbulence level, light intensity, water turbidity, and ventilation rate) are varied to resemble seasonal changes. At periodic intervals, the water temperature profile and the water level are measured in order to obtain the evaporation rate. Figure 15 shows results from a typical pair of experiments in which the light was set at full intensity for one hour and then turned off for an additional hour. All other parameters were held constant during these experiments. In one run, clear tap water was used on the working fluid and in another run, dye was added to the water. The extinction depth D is defined by,

$$R(z) = R_o e^{-z/D}$$

where R(z) is the downward flux of radiation at depth a, R_o is the flux

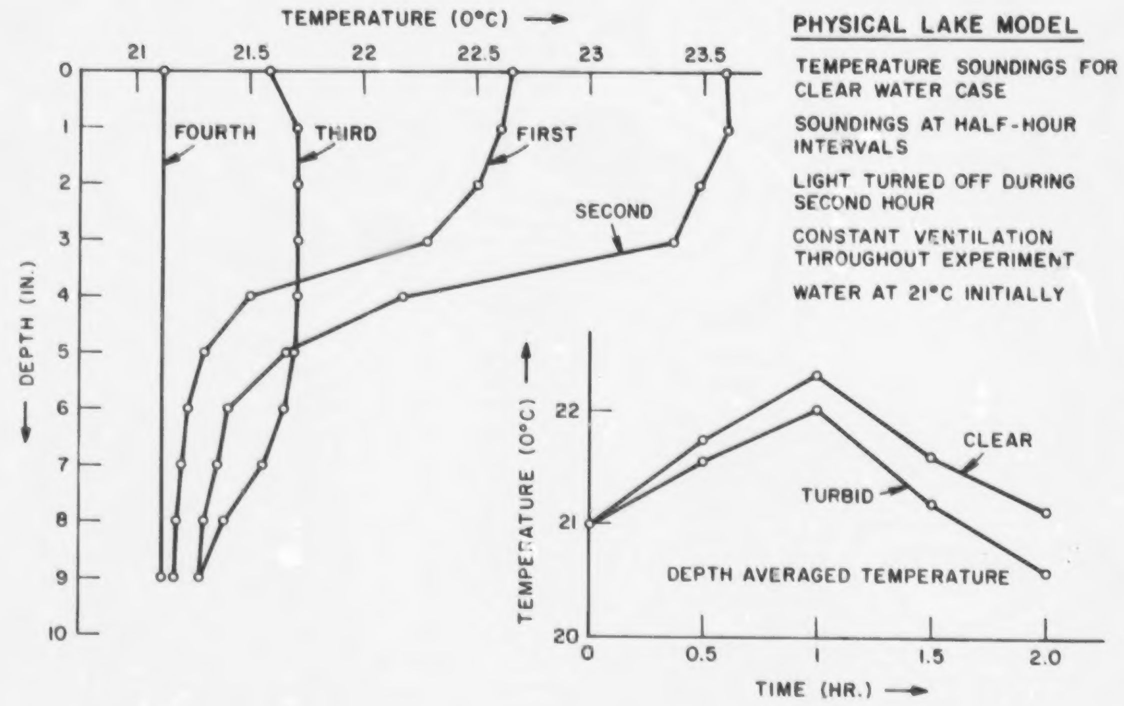


Figure 15. Results of two typical physical model experiments.

which has been absorbed at the surface, and D is the depth at which $R(z) = R_o/e$. D, a strongly wavelength dependent quantity, was measured in the visible range (0.35–0.65 μ) by means of a photometer (Weston 594) sounding. A value was estimated and averaged over all wavelengths by means of a calorimeter technique. For the "clear" experiment, D = 100 cm in the visible and 42.3 cm overall, including the strongly absorbing infrared portion of the input spectrum. For the "turbid" water, D = 6.99 cm in the visible and 0.78 cm overall. In Figure 15, a temperature series is presented made at half-hour intervals for "clear" water. The model can be seen to develop the three layer temperature profile characteristic of lakes and oceans during the late spring, summer, and early fall. The companion "turbid" experiment was initiated at the same temperature (21°C) and developed a similar temperature profile, but cooled steadily relative to the "clear" experiment. The curves at the lower portion of Figure 15 show the depth-averaged temperature for the two experiments. At the end of the two-hour experiment, the "turbid" system was 0.54°C cooler than the "clear" system.

In all the experiments a similar "turbidity cooling" effect was observed for depth-averaged temperature. In experiments in which the ventilation rate was low or zero, the surface waters of the "turbid" system warmed relative to the "clear" system. The depth-averaged temperature after a "seasonal" cycle, however, was cooler for the "turbid" system. An alternative explanation of the decreased temperature of the "turbid" experiment relative to the "clear" experiment shown in Figure 15 is that the humidity changed from run to run and caused an increased evaporative heat loss in the "turbid" experiment. Later studies, carefully controlled for ambient humidity, show the same "turbidity cooling" effect, but with a smaller magnitude. On the basis of the experiments reported here, the hypothesis that turbid lakes will cool relative to clear lakes is plausible in the sense that the effect can be observed in a laboratory system "similar" to real lakes. If the pollution of Lake Tahoe were to continue, it is possible that the lake will freeze. However, the crucial question, namely, how long would the observed increases in surface turbidity have to persist in order to freeze the lake, cannot be answered at this time, because little is known concerning the relative magnitudes of the various terms in the energy budget for both the model and the lake.

The next step in this study will be to establish the numerical magnitude of the "turbidity cooling" effect for real lakes so that the effect of a given increase of organic or inorganic turbidity can be predicted. The following approaches are now being made to the problem: (1) An automated limnological and meteorological station at Lake Tahoe which will provide information needed to estimate the heat budget of Lake Tahoe is being established. (2) A numerical model of heat transfer processes in lakes is being formulated. (3) An improved version of the physical model has been constructed which will be operated on a computer-controlled basis. This model can be installed on an existing rotating platform facility if it seems desirable to add rotation effects to the model.

GEOLOGY

Lake Tahoe lies in a deep, graben basin which is steep-sided and flat-bottomed. Its bathtub-like morphometry is interrupted on the sides by several canyons which resemble, on a smaller scale, the submarine canyons along the California coast. Several small lake mounts extend up from the lake bottom. Although the basin morphometry had been contoured by a U.S. Coast and Geodetic Survey using wire sounding in 1923 (Chart 5001), a more accurate bathymetric map was produced in conjunction with the present study by University of Southern California personnel in cooperation with University of California, Davis investigators.

The geological history of the Lake Tahoe basin is complex and the underwater geology was relatively unknown until the present studies were undertaken. Lake Tahoe lies in a deep basin formed both by tectonic and volcanic processes and subsequently modified by glaciation and sedimentary deposition. The basin is the southernmost in a series of tectonic depressions (grabens) that ran southeasterly from Mt. Lassen (Batemann and Wahrhaftig 1966). Sierra Valley to the north and Carson Valley to the east are dry basins formed in this manner.

Man has influenced the sedimentation rate at Tahoe on two major occasions. During the Comstock mining days many areas of the basin were logged. More recently the explosive building development in the basin has increased the sediment load greatly wherever new roads and houses have gone in. The sediment increase through development from the Upper Truckee River was estimated at twice the natural rate in the late 1960's (State of California Resources Agency 1969).

Methods

Investigation of the subaqueous geological features involved use of equipment for surface sounding and sediment sampling. Subsurface sounding and sediment coring was also included for detection of hidden geophysical features. Navigation on all across-lake runs and locations of piston cores and other bottom samples was accomplished by sextant triangulation on lakeshore landmarks.

A bathymetric map was constructed from a precision depth-recorder survey using a Gifft recorder and EDO transducer, seismic reflection profiles, and lead-line soundings from U.S. Geodetic Survey chart 5001. Supplemental soundings were taken with a recording Raytheon DE-721A Fathometer^{R} Depth Sounder. Continuous seismic reflection data of the extent of subsurface layering and sediment thickness were recorded by a Bolt Associates PAR model 600 air gun with a 1 cu. in. chamber firing 1400 psi, a model

1011 hydrophone streamer, and a model PA-7 preamp/filter. A sound velocity of 1463 $m \cdot sec^{-1}$ in water and 1524 $m \cdot sec^{-1}$ in sediments was used for depth and sediment thickness computations, respectively. Fault lines and other subsurface features such as volcanic intrusions were detected by towing a Varian rubidium magnetometer behind the boat which was wired to shipboard recording instruments.

Core subsamples for textural analysis were wet-sieved through a 62 μ Tyler sieve to separate the sand + gravel fraction (>62 μ) from the silt + clay fraction (<62 μ). The sand + gravel fraction was further separated by courser sieves, dried, and weighed in pre-tared aluminum dishes. The silt + clay fraction was filtered through pre-weighed GFA filters, oven-dried, and weighed. Separation of clay from the heavier silt was done by gravity settling and decantation of clay five times. Organic matter (chiefly pollen) flocculation problems were alleviated by H_2O_2 solubilization. Clay was classified as particles less than two microns to facilitate X-ray diffraction analysis. Silt fractions (2-62 μ) were air-dried and weighed in pre-tared aluminum dishes.

X-ray diffraction analysis of clay fractions was done on a G.E. XRD-5 unit. Four patterns were run for each sample with the following treatments: Mg^{++} saturated, solvated with glycerin, K^{+} saturated, and heated to 500°C. Sands were stained with sodium cobaltinitrate and amaranth for feldspar detection and examined microscopically to estimate mineral components. To aid in identification of mineral grains, selected samples were examined with a petrographic microscope.

Organic carbon in the top 0-2 cm of several cores was detected gasometrically. Samples were burned in a LECO induction furnace and the CO_2 released was measured with a Beckman infrared analyzer. Pollen and diatom frustule content in cores was estimated by microscopic examination of discrete subsamples. Diatom species and abundance were also determined for one complete mid-lake core. Age of core sediments by carbon dating was done by the Age Determination Laboratory of Isotopes, Inc.

Results

Quaternary History -

About 2 million years ago, volcanisms and tectonics closed the basin at the northwestern edge and began the formation of geological features as we know them today. Pleistocene glaciers along the south, west, and northern shores scoured and eroded basin topography from basin crests to the lake shore. The formation of Emerald Bay, Cascade Lake, and Fallen Leaf Lake indicate the extent to which glaciation reached the lower elevations. Less visible today, but highly significant to Tahoe basin topography, was the work of glaciers at the northwestern edge of the basin and intermittent ice-damming of the Truckee River outlet. On several occasions, the lake level rose as much as 250 m above its present elevation and glacial outwash deltas built up to a corresponding lake level. When the outlet ice dam eroded away or broke, a rapid lowering of the lake level brought about catastrophic slumping of the once-submerged deltas down the steep western and southern shores and some deltaic debris were carried out over the central lake floor (Hyne et al. 1972). This event apparently occurred several times during and at the end of three glacial periods.

Interglacial periods were characterized by a comparatively slow deposition of a well-layered "rain" of suspended fine sediments which "ponded" in depressions around the mid-lake bottom topography. Today only scattered tops of the slump deposits, covered by a thin layer of fine sediments, remain above the relatively flat central lake floor.

Terrestrial Geologic Features -

Rocks of the Tahoe basin are divided into four major categories (Fig. 16).

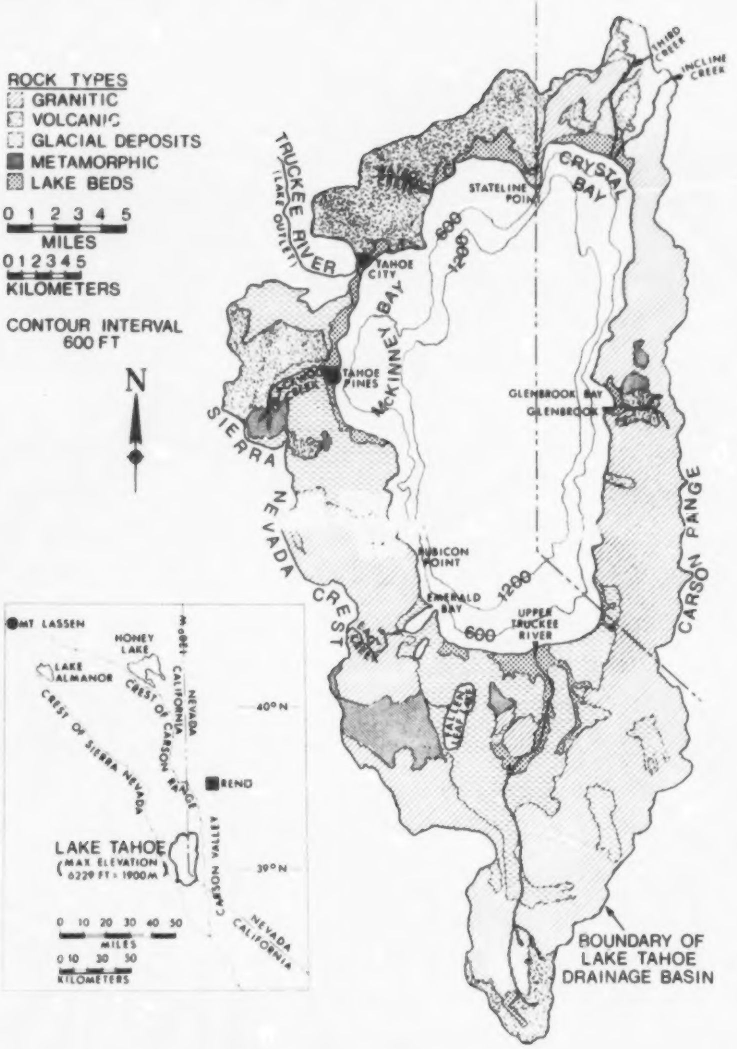

ROCK TYPES
GRANITIC
VOLCANIC
GLACIAL DEPOSITS
METAMORPHIC
LAKE BEDS
0 1 2 3 4 5
MILES
0 1 2 3 4 5
KILOMETERS
CONTOUR INTERVAL 600 FT
N
TRUCKEE RIVER (LAKE OUTLET)
TAHOE CITY
TAHOE PINES
McKINNEY BAY
STATELINE POINT
CRYSTAL BAY
THIRD CREEK
INCLINE CREEK
600
1200
GLENBROOK BAY
GLENBROOK
SIERRA NEVADA CREST
CARSON RANGE
RUBICON POINT
EMERALD BAY
UPPER TRUCKEE RIVER
FALLEN LEAF LAKE
BOUNDARY OF LAKE TAHOE DRAINAGE BASIN
MT LASSEN
HONEY LAKE
LAKE ALMANOR
CREST OF SIERRA NEVADA
CREST OF CARSON RANGE
120° W
CALIFORNIA
NEVADA
40° N
RENO
CARSON VALLEY
LAKE TAHOE (MAX ELEVATION 6229 FT = 1900 M)
39° N
0 10 20 30 40 50
MILES
0 10 30 50
KILOMETERS

Figure 16. Distribution of rock types in the Tahoe basin.

Granodiorite is the most abundant granitic bedrock and predominates along the mid-western lake shore, around the southern end of the basin at high elevations, and along most of the eastern side of the basin. Metamorphic rocks occur as roof pendants in the granitics at isolated high elevations on the east, south, and west sides of the basin. Volcanics occur primarily along the north and northwestern shores and at the remote south end of the basin. Recent volcanism (Holocene) is evidenced by the well-preserved cinder cones near Tahoe City.

Quaternary sediments, the fourth category, are glacier and lake bed deposits laid down or distributed during the pre-Wisconsin and Wisconsin periods of the Pleistocene glaciation. Four glaciations within that period affected the Lake Tahoe area. The Hobart, Donner Lake, and Tahoe glaciations (Birkeland 1964) are thought to have produced most of the present day relief above and below the lake surface. The more recent Tioga glaciation played a lesser role in formation and redistribution of deltaic slump deposits along the western and southern shores. Pleistocene glaciation was limited to the western Sierra Nevada side of the basin and a rain shadow produced by the mountains kept the eastern shore and Carson Range from experiencing glaciation.

Bathymetry -

The sub-surface relief of Lake Tahoe in Figure 1 indicates that the basin is steep-sided and fairly flat-bottomed. Two large shelf areas occur at the south end and on the northwest shore. Numerous canyons and gullies bisect the bottom contours. Some of these can be traced to the mouths of present day streams, but others show no link with terrestrial drainage patterns.

The east and west sides are fault scarps with slopes averaging about 30° although the fault lines are neither evident from seismic reflection profiles nor visible from land because of the glacial outwash cover.

The northern subsurface relief at North Stateline Point and Crystal Bay exhibit spectacular ridges of bedrock with slopes approaching nearly 45° and ponded sediments between them. The North Stateline bedrock trends northwesterly some 5 km before disappearing under central lake floor sediments.

The southern shore is characterized by a wide, shallow shelf which drops off rapidly after passing about 5-m depth at a slope of about 11°. Slump mounds occur all down the slope to the relatively flat central lake floor which is dotted with numerous high energy slump "lake mounds" (Goldman and Court 1968; Hyne, Goldman, and Court 1973). These mounds number at least 15 of significant size; the largest approaches 130 m in height and has a slope of 17°. The tectonic origin of these mounds from the times of glacial ice dam breakage appears to be supported by the nature of sediments surrounding the base of such mounds. The sediments are neither upbent nor downbent which indicates deposition after the mound formation. Volcanic origin is ruled out because magnetic field variations between the mounds and adjacent sediments are nearly non-existent.

Further evidence of the mound origins is revealed by piston cores. About 1 m is fine-grained turbidite characteristic of interglacial and Holocene depositional periods. Below that level, the sediment is a chaotic jumble of clay to cobble-sized fractions. The similarity of these mounds to the size and structure of off-shore oceanic mounds and abyssal hills of abyssal plains is striking (Menard 1964).

Geophysical Data -

Neither total sediment thickness nor maximum number of layers was recorded during the studies due to equipment limitations. However, indications are that central lake floor sediments are much more than 400 m thick in some areas, because no signs of bedrock were detected by seismic reflection equipment over a large portion of the mid-lake bottom. The well-layered surface sediment extends to only 40 m and alternate layers of jumbled, chaotic and level, well-layered sediments continue downward to the detection limit. Hyne et al. (1972) have estimated that the depositional rate is at least 12 cm·1000 $years^{-1}$.

Heavier glaciation of the western and southern portions of the basin has resulted in a larger deposit of sediments along the western bottom than is found below the eastern shore. The sediments also dip westward, indicating more extensive faulting along the western edge of the graben. The bottom from Sugar Pine Point to Dollar Point is a chaotic jumble of slump blocks. Seismic reflections of the southern edge of the lake basin indicate the presence of two or possibly three major deltaic sediment surfaces buried beneath the present delta. This supports the possibility that the three glaciations affecting Lake Tahoe basin topography constructed consecutive glacial outwash deltas which slumped and were buried by subsequent deltas.

Carbon dating of sediments has revealed that rapid deposition characterized the earliest stages of Tahoe basin formation. A core from mid-lake had an age of about 7000-8000 B.P. from the 250-580 cm depth. Volcanic ash layers above it date from around the time of the Mount Mazama eruptions (6000-7200 B.P.). The top 25 cm of the core was dated at about 2060 B.P. About 30 cm of recent sediments was lost during the coring operation for which no dates are available, possibly accounting for the age of the uppermost core sample.

Surface Sediments --

Investigation of mineral and biogenic components of the surface sediment at 40 sites reveals two main sediment types in Lake Tahoe. One is an organic ooze of postglacial origin, slowly deposited in flat-lying beds, homogenous in composition, containing a high proportion of diatoms and pollen and chloritic intergrades, and derived mainly from granitic rocks.

The granitic rocks predominate over about 70% of the basin (McGauhey et al. 1963). The other type is non-organic in origin with an inhomogenous texture, chaotic organization, rapid deposition during glaciation, high in vermiculite, mica, and montmorillonite. Its source is from both granitic and volcanic rocks. Pollen is absent or rare. Differentiation of the two sediment types was clear. Most samples were organic ooze composed of 50-90% diatoms and pollen. The non-organic sediment sites contained less than 10% organic material. Most of these sites were on the northwestern side of the basin and at lake mound locations.

It is notable that neither diatom species nor size variation was significant throughout a single 90 cm core taken from mid-lake for microscopic examination (Table 7). Curiously enough, there is a complete lack of Fragilaria crotonensis throughout the length of the core. This diatom is now the dominant type in Lake Tahoe, both in biomass and numbers. Because of core top disturbance during sampling, it is not known if this influx of a new dominant algal species is a current event or began in recent geological time. This discrepancy may signal a subtle ecological change in Lake Tahoe, but further samples will be needed for confirmation. It is possible that a gradual increase in the lake nutrient level is responsible. Hutchinson (1968, p. 483) notes that F. crotonensis is readily able to utilize nitrate-nitrogen at the expense of other species. Temperature, light, and species compositional changes may all have played an important role in the change.

Sediments in the coarse fraction (>62 μ) included many volcanics, notably hypersthene, feldspar basalts, sphene, hornblende, and quartz. The fine fraction (<62 μ) included montmorillonite and mica from volcanic sources and vermiculite and chloritic intergrades derived from the granitic rock which is dominant over about 67% of the basin.

Six tributaries, also samples for mineral type, mirror their drainage parent rock type in their sediment load. The Upper Truckee River,

TABLE 7. DIATOM SPECIES IN A 90 CM CORE TAKEN FROM MID-LAKE TAHOE.

FAMILY: BACILLARIOPHYCEAE

ACHNANTHES CLEVEI
    FLEXELLA
    LANCEOLATA
    NOLLII
    PERAGALLI

AMPHORA OVALIS

COCCONEIS DISCULUS
    PLACENTULA
    RUGOSA

CYCLOTELLA BODANICA
    OCELLATA
    STELLIGERA

CYMBELLA GRACILIS
    LANCEOLATA
    VENTRICOSA
    SINUATA
    PROSTRATA

DIATOMA ANCEPS

DIPLONEIS ELLIPTICA
    OCULATA
    FINNICA

EPITHEMIA SOREX
    TURGIDA
    ZEBRA

EUTONIA NAEGELII
    TENELLA

FRAGILARIA INTERMEDIA
    PINNATA
    CONSTRUENS VARBINODIS
    LEPTOSTAURON

FRUSTULIA RHOMBOIDES

GOMPHONEMA ACUMINATUM
    PARVULUM

HANTZSCHIA AMPHIOXYS

MASTOGLOIA SMITHII

MELOSIRA CRENULATA

MERIDION CIRCULARE

NAVICULA AURORA
    BACILLUM
    COCCINIFORMIS
    EXIGUA
    MUTICA
    PSEUDOSCUTIFORMIS
    PUPULA
    RADIOSA
    CAPITATA

NITZSCHIA FILLIFORMIS
    AMPHIBIA

OPEPHORA MARTYI

PINNULARIA BICEPS
    AESTUARII
    ABAUJENSIS

RHOICOSPHENIA CURVATA

RHOPALODIA GIBBA

STEPHANODISCUS ASTREA

SURIRELLA OVATA

SYNEDRA RADIANS
    RUMPENS
    ULNA
    INCISA

TABELLARIA FLOCCULOSA

TETRACYCLUS LACUSTRIS

Incline, and Eagle Creeks flow over mostly granitic rock while Blackwood and Watson derive their mineral content from volcanic sources. Glenbrook Creek traverses both types of rock. Figure 17 illustrates the percentages of coarse and fine mineral constituents found at major lake and stream sampling sites.

Lithology of the sediments falls into four basic types:

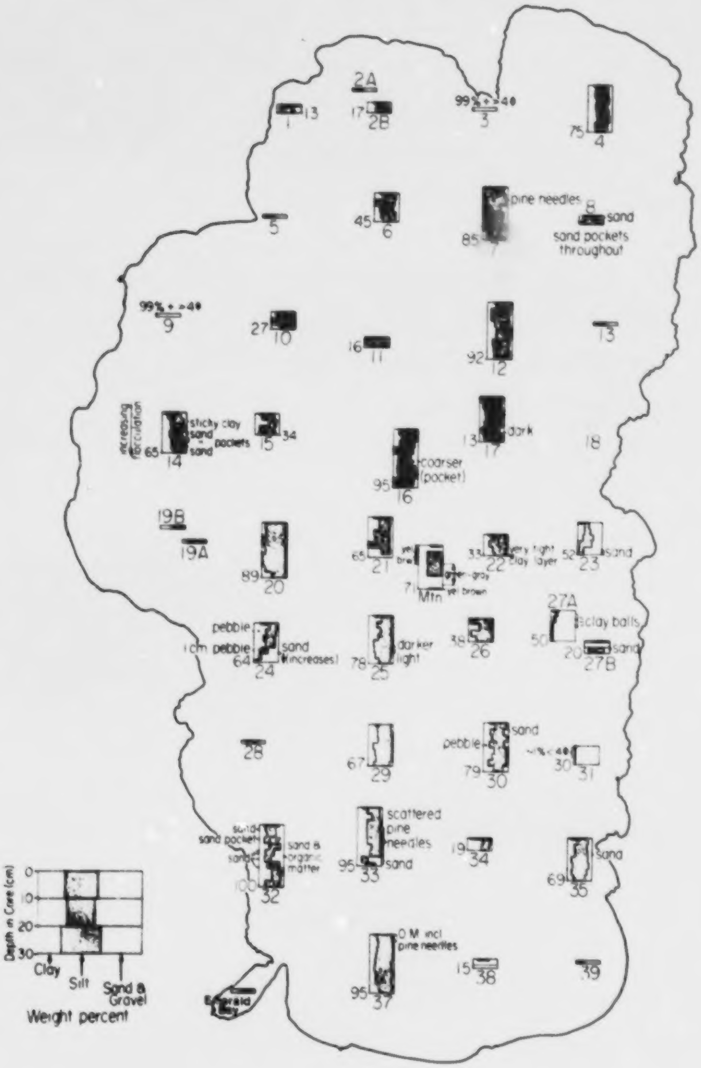
1. Well stratified, flat-lying sediments in the deepest central floor and "ponded" in depressions surrounding lake mounds. These are usually composed of homogenous organic type sediments, rich in diatoms and pollen, which result from slow deposition during interglacial periods.

2. Contorted, jumbled layers exposed in lake mounds rising in relief above the central floor. These sediments are texturally inhomogenous and non-organic in type.

3. Deltaic deposits on the steep slopes and periphery of the central floor. They occur chiefly on the western and southern shore in the form of high energy slump features. They are inhomogenous, chaotic and composed of coarser materials deposited rapidly in outwash deltas during glacial times and redistributed by slumping when the lake level fell rapidly.

4. "Bedrock" with little sediment cover is located in isolated spots along the fault scarp at North Stateline Point and in Crystal Bay. This type of granitic rock is also indicated by soundings off Emerald Bay and Zephyr Point.

Explanation for the non-uniform distribution of the biogenic components (pollen and diatoms) in the organic ooze possibly lies in their differing hydrodynamic properties. Court, Goldman, and Hyne (1972) infer from



2A
13
1
17
2B
99% + >4Φ
3
75
4
5
45
6
pine needles
85
7
8
sand
sand pockets throughout
99% + >4Φ
9
27
10
16
11
92
12
13
increasing flocculation
sticky clay
sand pockets
sand
65
14
34
15
13
dark
17
18
coarser (pocket)
95
16
19B
19A
89
20
65
21
yel brn
71
green-gray
yel brown
Mtn
33
very light clay layer
22
52
sand
23
27A
clay balls
50
20
sand
27B
pebble
1 cm pebble
sand (increases)
64
24
darker
light
78
25
38
26
28
67
29
sand
pebble
79
30
~1% < 4Φ
30
31
sand
sand pocket
sand
sand & organic matter
100
32
scattered pine needles
sand
95
33
19
34
sand
69
35
O M incl pine needles
95
37
15
38
39
Depth in Core (cm)
0
10
20
30
Clay
Silt
Sand & Gravel
Weight percent
Emerald Bay

Figure 17. Grain-size distribution in cores from Lake Tahoe. Coarse-grained samples (13, 23, 27, 31) reflect the steep, granitic eastern side-wall.

their analysis that diatoms are less transportable than pollen and less subject to windrowing at high energy wave and current sites. Because of this, pollen tends to accumulate at low energy sites and diatoms do not. It is also suggested that pollen could be selectively destroyed in an oxidizing environment, but this seems unlikely in Lake Tahoe because of high dissolved oxygen contents measured at all locations and depths.

The apparent lack of diatoms and pollen in sediments from periods of glaciation can be explained by lower lake and air temperatures which reduced aquatic and terrestrial growth seasons and areas. The biogenic materials produced were also heavily diluted by the tremendous increase in lithogenic materials through accelerated erosion and weathering.

The apparent dominance of chloritic intergrades derived from granitic sources in the organic ooze sediments is linked to previous glacial action on the two prominent basin rock types. Glaciation was evidently heavier in volcanic rock areas and, thus, more interglacial period erosion of weathered material occurred in the granitic areas and led to deposit of more chloritic minerals.

The present day surface sediment composition of Lake Tahoe has undoubtedly played an important role in selection of benthic flora and fauna and their distribution on the bottom. Not only is the type of substrate important, but the nutritive capabilities of the deposits may be critical. This is discussed in the following chemical section (V) on the nutritional effect of pollen to increasing primary productivity of Lake Tahoe (Richerson, Moshiri, and Godshalk 1970).

The processes of erosion and sediment deposition by basin streams have only recently come under intensive investigation. The State of California Resources Agency conducted sedimentation and erosion studies in the Upper Truckee River and Trout Creek watershed in 1967-1968. Accelerated erosion resulting in doubling of natural sedimentation rates was attributed to construction in developing areas on a relatively small percentage of the total watershed (State of California Resources Agency 1969). Far more dramatic sediment increases have been noted by Glancy (1971, 1973) on five creeks in the Incline Village area in Nevada. Development areas were estimated to yield 12-13 times more sediment than undisturbed areas over two water-years ending 30 September 1971. These studies are continuing in order to provide a valuable quantitative assessment of sediment yields during the period of "healing" of large areas of nearly completed construction in the watersheds.

The U.S.G.S. is conducting streamflow and sediment studies on several other major streams in the Tahoe basin. The most intensive study is being conducted cooperatively with the Tahoe Research Group (under the direction of Dr. Charles R. Goldman) in the Ward Valley watershed near Tahoe City. Standard methods of water discharge and sediment measurement and analysis are being combined with detailed research into the hydrogeochemical processes in the watershed. The primary goals of the project are to establish base water quality levels in Ward Creek prior to major recreational development, to relate development effects to possible changes in water quality and to recommend methods of preserving water quality during and after development.

The complete 1972-73 water-year of data has been compiled and is in the process of analysis. Preliminary comparison of data from Ward and Incline Creeks reveals that sediment concentrations in Incline were many times higher than in Ward Creek under comparable flow conditions. Disturbance by construction in Ward Valley is as yet minimal. The continuing applied and basic research program of the Tahoe Research Group is providing up-to-date assessment of changes in quantity and quality of sediments and dissolved nutrients in Ward Creek as the terrestrial environment of the valley is transformed from natural to developed. The ultimate intensity of the development is as yet unknown.

SECTION V

LAKE WATER CHEMISTRY

Water chemistry analyses at many locations reveal a remarkable seasonal and areal uniformity in water quality for most parts of the lake. Nearshore variations tend to be more pronounced, localized, and transient especially in the vicinity of tributary stream inflows. Although 90-95% of Lake Tahoe's surface and deeper waters remain of extremely high water quality, inshore sampling reveals some disturbing increases in the concentration of important bio-stimulatory nutrients. See Section VII on tributary-lake transects for further evidence of this condition.

INVESTIGATIONS

In general, water chemistry of the main body of Lake Tahoe is a much poorer indicator of lake fertility than the phytoplankton and periphyton communities that utilize the nutrients. If one were to base opinions as to Tahoe's present and future condition strictly on these parameters, one would be forced to the conclusion (as has already happened) that the water quality has not deteriorated. The evidence presented in Sections VI, VII, VIII, and IX of this report clearly evidence the fact that the lake has already undergone a degree of cultural eutrophication and will continue to increase in fertility at an unnaturally high rate until population, vegetation, and land management controls stem the flow of nutrients from its many disturbed watersheds. Sewage diversion was a major step in this direction. Drainage and vegetation control must now follow.

Methods

A variety of methods has been used in the chemical analyses presented in this section. Most of the standard methods are not of sufficient sensitivity for working in the low parts per billion (or $\mu g \cdot l^{-1}$) range typical of Lake Tahoe's waters. Considerable attention in the research program was directed towards modifying existing procedures to deal with Tahoe's ultra-low levels. These chemical methods with their modifications are included as Appendix E of this report. Ammonia determinations in Tahoe have been a particularly difficult problem. Current levels have been near zero and it is difficult to get blanks as low in ammonia as the lake water. For this reason, the ammonia determinations for the lake have not been included in this report. Both nitrate and phosphate methods were changed after 1968. Comparisons with the 1968 data are therefore less reliable than subsequent years.

Oxygen samples were collected in conjunction with the temperature and water chemistry samples for our study of Lake Tahoe deep water limnology. A series of three Van Dorn, non-metallic water samplers were placed on the hydrographic wire two meters above each reversing thermometer frame and tripped in sequence with the thermometers. Samples were drawn off immediately upon sample retrieval into 125 ml Pyrex bottles fitted with tapered, ground-glass stoppers and teflon stirring bars. Each calibrated bottle (nearest 0.1 ml) was stoppered and then opened for immediate addition of 1.0 ml of $MnSO_4$ and alkaline-iodide. Samples were stored in a cool, dark chest and acidification and titration done within 2-4 hours. The method used a micro-Winkler technique (Carpenter 1965) employing a 5-place micro-burette. All depths were sampled in triplicate and oxygen results computed as the average of the three readings. Thiosulfate was standardized using 0.1 N KIO_3 taken from ampoules which were run before, during, and after sample titrations.

The determination of total particulate carbon as a measure of seston content in Lake Tahoe was carried out during the course of the study at every index station and for most synoptics and other specialized studies. A 2-liter sample was taken in opaque glass bottles at each sampling depth and stored under refrigeration. The sample was split into 1-liter aliquots and passed through a 25 mm Whatman GF/C glass-fiber filter under 20 lb. vacuum pressure. The glass-fiber filters were pre-combusted in a muffle furnace at 550°C to remove any residual carbon contamination. The duplicate filters were placed in aluminum weighing dishes scribed with date, depth, and volume of sample and kept frozen until induction furnace analysis (Armstrong, Goldman, and Fujita 1971). Care was taken not to handle the filters or write on them since any oil or ink would increase the carbon content of the filters dramatically.

Results

Synoptic and Index Stations -

Since most synoptic stations and the index station are taken in areas of the lake where depths are at least 20-150 m, they represent chemical conditions typical of most of the lake. Tables 8-10 provide water column values for total phosphorus, nitrate-nitrogen, and total iron present at the index station (depth 105 m) over the 1968-1971 period. Total phosphorus concentration is usually well below 8 $\mu g \cdot l^{-1}$ (or ppb) from 0 to 150 m while nitrate-nitrogen levels are very low and range from 1 to 25 $\mu g \cdot l^{-1}$. Total iron levels are also characteristically low and typically remain below the 7 $\mu g \cdot l^{-1}$ level. The 14 $\mu g \cdot l^{-1}$ measured at 75 m on 22 December 1970 probably represents a contaminated sample.

Trends in the average nutrient concentration in the water column at the

TABLE 8. TOTAL PHOSPHORUS (µg/l) AT THE INDEX STATION OF LAKE TAHOE, 1968-1971.

	1968											1969	
DEPTH M	FEB 20	FEB 29	MAR 6	MAR 13	MAR 26	MAY 1	JUN 5	JUN 12	JUN 26	JUL 11	JUL 31	JUL 24	NOV 24
0	1.7	0.9	1.5	1.7	1.9	1.5	1.9	1.4	1.8	1.5	1.9	3.9	2.6
2	---	1.8	3.1	1.9	1.7	2.4	1.9	1.5	1.9	---	2.3	---	---
5	0.7	2.8	1.6	1.4	1.5	2.2	2.1	1.6	1.8	2.0	2.7	---	4.9
10	---	2.5	1.6	1.4	1.4	1.6	1.9	1.6	1.6	1.9	2.1	2.9	2.0
15	1.5	2.4	1.7	1.2	1.4	1.6	---	---	1.8	2.2	2.0	---	2.6
20	---	2.0	---	1.7	1.4	---	1.9	1.9	1.8	2.0	2.5	8.2	2.6
30	---	1.7	3.4	1.7	1.6	1.1	1.9	1.6	1.9	---	2.3	6.9	2.0
40	---	1.0	0.9	---	1.6	1.1	---	---	---	---	2.3	---	---
50	1.8	1.5	---	1.6	1.8	1.6	1.7	1.5	1.6	1.7	2.5	2.6	2.6
60	---	1.2	1.5	1.6	1.2	1.6	---	---	---	---	1.9	---	---
75	---	1.4	1.3	1.9	1.2	1.5	---	1.4	1.6	2.0	2.9	---	2.6
90	1.2	1.4	1.1	1.1	---	1.6	2.7	2.2	1.7	2.0	2.1	---	---
105	---	---	---	0.5	---	---	---	1.8	1.7	2.3	2.1	7.2	1.6

	1969	1970										1971	
DEPTH M	DEC 16	JAN 19	FEB 10	FEB 28	APR 2	JUL 1	JUL 24	AUG 11	SEP 2	OCT 2	DEC 22	JUL 14	AUG 17
0	2.6	2.9	2.9	5.2	4.8	6.8	5.0	7.0	6.1	5.4	1.2	6.3	3.3
2	---	---	---	9.1	4.6	---	4.9	3.7	5.7	5.2	1.3	5.4	3.5
5	4.2	3.4	2.8	3.9	5.0	6.7	4.4	4.7	6.3	4.3	1.2	4.6	3.3
10	2.0	3.2	2.8	4.2	4.6	6.2	4.5	2.5	6.0	4.1	1.1	4.4	3.1
15	2.6	2.2	1.8	5.2	3.9	---	4.2	2.5	5.2	4.3	1.3	5.1	2.3
20	1.6	2.2	5.2	5.2	5.3	6.0	3.8	4.0	5.2	4.4	1.4	5.8	2.0
30	2.3	3.7	3.0	5.2	6.7	6.2	3.7	3.7	5.4	4.3	2.4	6.3	2.4
40	---	---	---	5.2	7.9	6.3	2.9	9.6	4.8	4.3	1.2	6.5	2.6
50	2.3	2.0	6.6	4.6	8.0	3.5	2.7	7.0	4.7	4.5	1.1	6.2	2.9
60	---	---	---	5.2	6.9	6.6	3.0	6.8	4.4	4.3	0.8	5.4	2.8
75	1.3	2.1	5.4	4.3	6.2	7.6	3.7	12.0	4.2	4.3	1.1	5.8	3.2
90	---	---	---	4.9	5.1	8.8	4.1	12.2	4.3	4.4	0.8	6.3	3.3
105	5.9	2.1	3.7	---	3.9	10.2	5.1	13.4	4.1	4.6	0.8	6.3	3.5

TABLE 9. NITRATE-NITROGEN (μg/l) AT THE INDEX STATION OF LAKE TAHOE, 1968-1971.

	1968											1969	
DEPTH M	FEB 8	FEB 20	FEB 29	MAR 6	MAR 13	MAR 26	JUN 5	JUN 12	JUN 26	JUL 11	JUL 31	JUL 24	NOV 24
0	15.0	11.0	10.0	13.0	---	10.0	8.0	19.0	20.0	15.0	12.0	0.0	5.0
2	---	---	---	---	13.0	---	9.0	---	---	---	12.0	---	---
5	12.0	11.0	11.0	---	---	12.0	---	---	---	21.0	13.0	---	5.2
10	---	---	---	11.0	---	---	11.0	23.0	12.0	23.0	13.0	0.0	5.0
15	13.0	11.5	---	---	---	---	---	---	---	25.0	12.0	---	5.2
20	---	---	---	---	13.0	13.0	---	---	---	19.0	13.0	0.0	4.7
30	21.0	11.5	---	11.0	---	---	10.0	24.0	11.0	---	12.0	0.0	5.4
40	---	---	13.0	---	---	---	---	---	---	---	13.0	---	---
50	13.5	12.0	---	9.0	---	11.0	---	---	---	23.0	11.0	0.0	5.0
60	---	12.0	---	---	11.0	---	---	16.0	9.0	---	11.0	---	---
75	---	---	---	---	---	---	12.0	---	---	19.0	9.0	---	4.5
90	14.5	12.0	14.0	10.0	10.5	10.0	---	14.0	9.0	20.0	13.0	---	---
105	---	---	---	---	10.0	6.0	23.0	12.0	8.5	23.0	26.0	0.2	10.4

	1969	1970									1971	
DEPTH M	DEC 16	JAN 19	FEB 10	FEB 28	APR 2	JUL 1	JUL 24	AUG 11	SEP 2	OCT 2	JUL 14	AUG 17
0	1.1	10.7	3.1	11.8	6.7	2.8	3.0	3.2	1.7	6.2	5.3	4.1
2	---	---	---	11.6	---	---	4.2	3.0	1.6	5.9	5.6	3.7
5	0.9	8.3	2.1	12.4	4.6	2.1	2.1	2.6	1.8	5.3	5.6	3.5
10	1.4	8.8	3.3	11.6	---	2.7	1.7	2.8	1.6	5.0	3.8	2.9
15	1.1	9.5	3.3	11.7	5.0	---	1.6	3.0	1.4	5.5	3.8	2.6
20	0.9	8.7	4.1	12.1	---	1.7	2.1	2.5	1.4	5.8	3.4	2.1
30	1.4	8.2	3.3	11.9	5.0	3.6	1.5	2.6	1.5	5.1	3.8	2.5
40	---	---	---	12.3	---	5.2	2.0	2.8	1.6	4.7	3.8	2.9
50	1.4	9.6	3.4	13.4	5.2	1.6	1.8	2.3	1.4	4.2	4.3	3.0
60	---	---	---	12.7	---	1.7	1.7	2.9	1.3	4.1	4.2	3.6
75	1.6	10.0	3.8	14.3	5.9	2.4	1.8	2.9	1.3	3.8	4.2	3.3
90	---	---	---	15.1	---	2.7	2.5	2.8	0.9	3.6	3.8	3.4
105	5.6	9.9	[illegible]	15.4	5.4	5.7	3.5	2.9	0.5	3.7	4.1	3.7

Table 10. Iron (µg/l) at the index station of Lake Tahoe, 1970-1971.

	1970	1971	
Depth M	Dec 22	Jul 14	Aug 17
0	0	2	2
2	2	1	2
5	0	1	1
10	0	1	2
15	1	1	2
20	0	1	2
30	5	1	2
40	7	1	2
50	3	1	2
60	0	1	2
75	14	1	2
90	7	1	2
105	0	1	2

index station are discernable. Phosphorus levels were lower (<2 $\mu g \cdot l^{-3}$) and nitrate levels higher (10-20 $\mu g \cdot l^{-1}$) in 1968 than in later years. Phosphorus values were from 2 to 5 $\mu g \cdot l^{-1}$ and nitrate levels fell to 1-10 $\mu g \cdot l^{-1}$ in 1969. The pattern was similar in 1970. Phosphorus levels were generally less in 1971 than the two previous years and nitrate concentration remain low. Iron levels were similar in 1970 and 1971.

Lake-wide concentration levels of nitrogen and phosphorus are given in Table 11. Chemical analyses during synoptic studies over the four-year period indicate several interesting points: (1) Nitrate levels are generally as low or lower than total phosphorus concentrations at all locations. (2) Near-shore locations have slightly higher N and P levels than deep water stations. (3) There is more year-to-year variation in nutrient levels at the littoral stations.

The amount of total particulate carbon found in Lake Tahoe varies seasonally by a surprisingly small amount (Table 12). Values in 1970 averaged around 50 μg $C \cdot l^{-1}$ and ranged from 34 to 145 μg $C \cdot l^{-1}$. Apparently, seasonal changes in seston form do not cause large variations in carbon content throughout the water column.

Deep Water Chemistry -

A deep water station in mid-lake was sampled during 1970 and 1971. Table 13 shows the depletion of nitrate-nitrogen in the euphotic zone with high levels present from about 200 m down in January 1970. There is evidence from the nitrate distribution that mixing may have occurred in the late spring of 1971. The utility of using nitrate distribution as evidence of deep mixing has been demonstrated by Paerl et al. (1974).

Total phosphorus is much more uniformly distributed with depth than nitrate (Table 14). In July 1970, however, it shows the same distribution

Table 11. Water chemistry (µg/1) at the synoptic stations of Lake Tahoe, 1968-1971.[1]

	Total Phosphorus				Nitrate-Nitrogen			
Station Location	1968	1969	1970	1971	1968	1969	1970	1971
Index (Tahoe Pines)	3.7	11.8	11.0	3.3	5.0	4.5	6.0	2.0
General Creek	4.0	14.2	11.3	3.6	6.4	3.2	6.1	2.3
Rubicon Point	3.8	16.0	9.9	3.4	5.0	2.2	4.9	2.3
Emerald Bay	4.1	11.7	10.1	17.1	4.8	1.3	4.1	4.5
Camp Richardson	3.8	22.5	7.8	8.1	5.3	2.2	5.7	6.2
Tahoe Keys	---	67.0	23.2	24.4	---	2.0	6.1	14.4
South Tahoe	4.0	32.0	9.4	14.5	4.8	2.2	6.3	8.2
Al Tahoe	4.0	20.7	10.5	13.2	4.4	2.0	5.6	5.3
Bijou	4.0	22.5	12.4	12.8	4.8	3.8	5.1	3.5
Elk Point	3.7	19.5	6.6	4.2	4.2	2.5	5.4	2.6
Pelagic (South Shore)	4.3	10.2	6.0	2.4	4.2	3.2	4.9	2.3
Zephyr Cove	3.7	7.2	9.6	2.6	5.3	2.5	4.8	2.4
Cave Rock	3.8	7.8	8.8	3.6	3.4	3.0	4.5	2.8
Pelagic (South)	---	8.5	6.9	2.5	---	2.5	5.3	2.1
Glenbrook Bay	3.8	14.8	9.4	3.8	4.0	5.0	6.0	3.1
Pelagic (Midlake)	4.5	11.2	7.2	2.6	4.0	2.5	6.6	2.3
Pelagic (Midlake)	4.1	9.0	6.4	2.3	3.1	2.5	4.8	2.3
Pelagic (Midlake)	3.9	13.8	5.5	2.0	2.8	3.8	4.2	2.3
Skunk Harbor	3.9	27.7	5.3	3.6	5.0	5.0	5.1	2.6
Sand Harbor	3.8	16.8	7.6	4.3	5.2	3.2	5.6	4.6
Incline Creek (East)	3.8	17.2	10.4	8.7	4.4	3.5	5.2	7.0
Incline Creek (Mouth)	3.8	9.3	10.0	10.8	4.5	3.5	4.7	7.6
Incline Creek (West)	3.8	11.5	9.4	11.7	5.4	6.2	4.4	7.3
Crystal Bay	---	11.3	6.6	7.5	---	5.8	4.2	5.3
North Stateline	3.7	31.5	6.9	8.1	4.8	7.5	4.8	3.5
Pelagic (Crystal Bay)	---	11.3	7.0	8.6	---	5.8	4.7	4.8
Pelagic (North Stateline)	4.0	10.8	5.5	2.4	3.8	4.0	4.3	2.3
Kings Beach	---	14.2	6.4	4.2	---	2.5	4.4	3.5
Carnelian Bay	3.7	13.8	5.5	4.6	5.3	2.8	4.9	2.9
Dollar Point	3.6	11.2	5.4	3.3	5.6	3.5	4.8	3.1
Tahoe City	4.4	9.0	9.0	3.5	5.2	2.5	4.0	3.2
Pelagic (Tahoe City)	---	13.4	4.4	2.9	---	3.0	4.0	2.3
Ward Creek	---	17.0	7.1	3.3	---	2.2	3.5	2.4
Average[2]	3.9	15.1	7.9	5.6	4.6	3.5	5.0	3.7

[1] 1968 values are based on an average of one synoptic, 1969 on four, 1970 on six, and 1971 on one.

[2] Excluding Emerald Bay and Tahoe Keys.

TABLE 12. PARTICULATE CARBON (µg/l) AT THE INDEX STATION OF LAKE TAHOE, 1968-1971.

Depth M	1968 Sep 11	Sep 17	Oct 19	Dec 1	Dec 7	Dec 22	1969 Jan 16	Feb 1	Feb 15	Mar 2	Mar 15	Mar 30	Apr 25	May 9	May 23
0	68.3	50.7	56.7	87.5	40.0	72.5	21.2	34.9	25.4	53.8	51.2	37.6	21.1	43.4	52.0
2	44.4	30.2	32.4	22.5	37.5	55.0	19.4	21.9	31.4	40.8	61.4	21.9	20.1	41.0	49.4
5	43.3	29.9	37.8	65.0	25.0	46.0	19.8	17.2	24.5	29.8	66.7	35.6	23.9	46.7	53.7
10	34.2	28.7	27.3	37.5	27.5	55.0	16.7	24.1	20.8	21.9	54.3	36.9	39.3	42.7	65.2
15	30.6	27.9	29.0	40.0	27.5	55.0	20.4	20.8	32.5	31.7	56.4	40.0	40.7	50.1	78.3
20	40.6	19.0	28.3	55.0	62.5	37.5	21.5	25.3	66.2	11.8	32.4	27.2	36.9	53.9	71.2
30	37.3	20.7	21.3	10.0	17.5	77.5	21.5	20.8	13.4	43.7	37.9	24.0	36.5	58.6	71.6
40	38.1	23.2	23.8	12.5	25.0	50.5	24.3	26.5	11.9	65.3	24.0	36.0	33.6	57.0	73.0
50	35.2	34.7	19.2	42.5	37.5	37.5	23.5	27.7	15.6	27.2	24.6	33.8	41.2	53.8	73.7
60	32.0	26.8	37.0	20.0	47.5	40.0	25.7	28.3	10.7	44.7	46.8	82.0	29.6	65.2	82.1
75	35.5	28.5	36.3	45.0	62.5	35.0	23.2	36.6	13.0	38.1	36.6	74.2	32.7	62.6	69.1
90	34.4	31.0	35.8	75.0	25.0	45.0	17.2	31.0	39.3	32.9	42.8	70.0	26.3	81.4	77.5
105	36.9	38.5	30.0	70.0	27.5	45.0	21.1	41.9	68.8	31.0	39.2	77.6	33.3	20.8	90.2

Depth M	1969 Sep 23	Oct 10	Oct 22	Oct 28	Nov 12	Nov 23	Dec 5	Dec 16	Dec 26	1970 Jan 6	Jan 30	Feb 10	Feb 23	Feb 28	Mar 10
0	57.0	42.3	38.0	36.0	37.1	66.2	91.0	57.5	47.5	60.0	36.5	34.0	53.5	62.2	45.5
2	47.6	52.8	41.3	33.4	32.2	66.0	56.5	62.5	33.0	48.0	32.0	36.5	39.0	78.6	41.0
5	73.7	44.3	45.1	38.8	37.0	39.5	48.0	75.0	24.5	45.5	25.0	42.0	45.0	47.0	50.0
10	45.3	36.0	40.8	36.0	35.1	36.0	35.0	56.5	29.0	40.5	31.0	32.0	39.5	48.5	49.0
15	39.0	30.1	31.4	35.7	35.8	39.5	28.0	44.0	24.0	39.0	26.0	48.0	42.5	49.0	62.2
20	38.3	34.4	48.7	36.8	39.6	86.0	142.5	120.0	123.0	112.0	27.5	41.0	62.0	51.6	38.5
30	43.0	38.1	49.4	32.1	35.8	48.0	32.5	35.0	33.5	57.2	32.5	47.5	39.0	37.3	37.3
40	49.1	36.8	45.8	37.9	34.4	34.4	40.5	65.0	47.5	46.7	65.0	43.0	43.0	68.2	44.7
50	51.5	30.2	47.2	39.6	37.5	40.0	30.5	50.0	33.0	59.0	29.0	85.5	100.0	44.0	82.1
60	41.5	44.3	49.8	43.0	34.6	37.0	36.5	40.0	33.0	44.6	32.0	38.5	63.0	----	54.4
75	36.0	32.0	53.0	41.7	34.3	34.4	36.5	46.0	59.5	42.7	39.5	37.5	53.5	62.0	55.0
90	30.4	35.9	42.2	42.6	31.9	31.0	36.0	35.5	28.5	37.5	26.5	31.5	43.0	62.6	37.9
105	37.0	36.4	41.9	40.7	37.4	36.0	66.0	41.5	29.5	40.0	32.0	35.0	63.0	50.1	34.5

Depth M	1970 Aug 11	Aug 17	Aug 24	Sep 8	Sep 18	Sep 23	Oct 2	Oct 14	Nov 10	1971 Jan 8	Jan 21	Feb 2	Feb 12	Feb 22	Mar 7
0	41.5	38.0	35.5	67.0	63.0	59.5	54.9	31.5	76.0	67.5	71.0	82.0	69.5	60.0	65.9
2	33.0	48.0	27.9	47.0	54.5	53.0	53.5	37.0	49.0	83.0	74.0	68.5	42.0	65.0	70.6
5	36.5	44.0	30.0	57.5	61.0	58.5	52.1	33.5	50.5	74.5	116.0	79.0	50.0	58.0	52.1
10	39.0	43.0	27.9	55.5	53.5	60.0	63.4	28.0	56.0	87.5	70.0	74.5	29.5	61.0	55.1
15	46.0	53.0	49.0	60.0	55.0	60.5	53.5	30.0	64.0	77.0	58.5	65.5	45.5	88.5	57.5
20	37.5	43.5	32.1	49.5	55.0	49.0	53.5	43.0	83.0	61.0	66.5	68.0	41.0	54.5	59.9
30	45.5	56.5	37.2	58.5	68.5	54.5	52.8	46.5	77.0	73.5	72.0	60.0	44.0	54.5	57.5
40	39.0	48.5	31.5	61.5	59.5	53.5	68.5	41.5	83.0	78.5	76.5	63.0	76.0	40.0	50.8
50	49.0	52.5	41.3	47.0	64.5	54.0	70.0	46.5	92.0	74.5	57.0	74.0	67.5	43.5	53.5
60	45.5	61.5	58.0	51.0	75.0	58.5	73.0	44.0	89.0	72.0	118.0	60.5	56.5	51.5	52.1
75	59.0	56.5	63.0	63.5	60.5	49.0	85.0	41.5	90.0	92.0	73.5	103.0	47.5	58.0	47.7
90	65.5	82.5	39.2	52.5	76.0	44.0	73.0	48.5	73.0	100.0	91.5	66.5	41.5	47.0	57.2
105	47.0	50.0	43.8	54.5	79.0	43.0	60.6	31.5	75.0	88.0	68.0	85.0	28.5	60.0	46.7

TABLE 12. CONT'D.

1969

DEPTH M	JUN 7	JUN 20	JUL 1	JUL 8	JUL 22	JUL 24	JUL 30	AUG 5	AUG 14	AUG 20	AUG 28	SEP 3	SEP 9	SEP 15
0	35.3	47.7	29.3	46.6	57.8	68.4	47.9	72.7	52.0	42.1	89.7	56.2	41.0	30.5
2	27.2	31.3	38.4	48.5	44.8	59.2	43.4	52.7	49.0	58.1	56.2	51.9	34.3	27.4
5	53.2	34.5	65.9	49.6	55.0	50.6	43.3	56.2	53.9	60.8	51.4	59.3	32.2	48.3
10	53.0	19.4	84.6	43.5	49.1	43.3	40.4	42.8	48.0	71.2	48.9	44.1	36.6	26.2
15	46.8	41.4	79.2	59.3	47.9	46.5	37.5	43.5	37.2	55.3	53.0	47.0	44.3	32.7
20	78.5	48.0	90.3	55.2	41.3	38.3	41.8	36.1	34.6	42.3	52.9	61.4	34.2	46.4
30	86.3	58.2	79.5	37.1	50.2	38.8	26.1	47.1	44.8	47.8	55.1	59.0	44.8	33.5
40	81.0	53.7	72.9	41.1	26.3	49.1	21.3	48.3	47.8	49.9	57.5	46.9	47.5	30.6
50	72.4	57.8	70.3	41.8	23.9	40.9	38.2	56.0	55.9	48.7	64.6	43.4	42.6	33.6
60	81.4	43.7	64.5	55.7	30.8	60.1	33.1	47.1	47.0	52.1	52.1	39.9	46.9	38.8
75	62.1	27.3	60.8	42.5	23.1	43.0	30.6	37.1	44.0	53.7	58.8	40.3	38.4	36.7
90	53.2	13.1	56.9	42.7	19.8	36.3	21.9	57.6	25.6	43.2	41.1	36.0	35.9	33.1
105	56.1	15.8	57.2	42.2	23.4	29.5	38.2	51.0	32.6	37.8	52.1	32.9	32.4	29.5

1970

DEPTH M	MAR 23	APR 2	APR 15	MAY 2	MAY 13	MAY 25	JUN 4	JUN 16	JUL 1	JUL 7	JUL 14	JUL 20	JUL 24	JUL 31
0	37.5	55.5	58.0	41.0	53.5	38.0	38.8	36.0	82.0	56.0	47.0	43.5	37.9	23.0
2	30.5	53.0	53.3	69.0	41.5	50.0	28.0	26.0	59.0	48.0	41.2	43.5	33.9	25.0
5	35.0	43.5	52.6	80.5	39.5	35.3	35.0	29.0	35.0	52.5	39.0	47.4	39.0	31.5
10	31.5	43.5	57.0	69.5	33.0	33.0	40.5	36.0	46.5	48.0	39.1	47.4	39.0	22.5
15	25.5	41.0	56.0	72.0	34.0	38.0	71.0	42.5	78.0	50.5	43.5	39.0	46.5	30.0
20	35.0	57.0	53.0	71.0	48.0	35.0	43.7	29.5	63.0	46.0	39.9	38.0	38.0	34.5
30	47.5	35.0	50.2	61.5	47.0	38.5	67.4	37.5	50.0	54.5	39.9	42.0	38.0	43.5
40	55.0	46.5	51.9	81.0	43.5	39.1	146.0	56.5	71.5	71.0	57.3	39.0	40.2	30.5
50	50.0	55.5	66.5	67.0	78.0	66.5	71.3	47.5	62.0	60.0	65.0	37.4	43.1	45.5
60	37.5	50.0	55.5	52.5	30.0	40.5	82.2	46.0	70.0	67.5	53.2	53.0	47.9	39.0
75	93.5	59.5	49.3	61.5	34.5	47.0	100.3	53.5	47.0	69.0	61.1	51.0	49.0	50.0
90	35.5	48.0	55.0	59.5	33.0	50.0	83.0	45.0	38.0	64.5	68.5	55.4	42.1	51.5
105	31.0	34.0	28.4	55.5	23.5	48.3	48.4	40.0	36.0	62.5	44.0	70.0	59.5	34.0

1971

DEPTH M	MAR 17	APR 2	APR 13	APR 23	MAY 5	MAY 19	JUN 1	JUN 14	JUN 25	JUL 1	JUL 8	JUL 14	AUG 24
0	100.2	106.1	110.1	72.5	73.2	120.6	104.0	80.5	73.1	94.3	61.4	66.6	126.8
2	107.8	85.1	96.2	82.2	80.5	74.0	86.0	93.3	64.6	65.4	53.5	55.0	88.1
5	81.9	86.5	98.6	69.6	105.1	63.7	80.5	79.7	67.5	62.2	54.8	63.2	94.0
10	86.4	85.1	99.3	92.9	83.6	77.2	96.5	98.3	78.8	60.5	75.7	53.6	91.1
15	81.5	90.8	92.5	94.0	72.1	76.0	92.0	88.4	84.0	56.2	60.1	78.2	156.6
20	85.0	84.7	99.3	84.0	102.0	87.6	133.0	102.4	67.9	51.8	65.3	54.4	120.8
30	87.8	87.6	91.9	104.0	104.3	79.6	117.0	98.3	74.5	44.2	62.7	58.6	126.8
40	77.4	89.7	107.1	85.1	76.7	84.0	89.0	98.3	79.5	55.6	62.7	77.6	120.8
50	102.3	97.2	106.6	84.4	107.0	87.6	67.5	83.0	84.4	72.5	77.0	71.0	103.0
60	87.1	107.9	96.2	71.3	81.3	83.6	55.0	59.5	81.6	75.8	97.9	69.6	108.9
75	83.6	90.8	122.7	89.6	108.9	88.0	62.0	57.8	91.5	63.2	87.5	67.3	97.0
90	69.8	92.2	97.5	62.2	90.5	79.2	45.0	54.1	84.4	54.0	92.0	56.5	123.8
105	51.1	52.9	84.5	71.1	123.1	129.0	44.0	46.2	66.0	48.5	65.3	55.2	103.0

TABLE 13. NITRATE-NITROGEN (μg/l) AT THE MID-LAKE STATION OF LAKE TAHOE, 1970-1971.

	1970					1971										
DEPTH M	JAN 2	FEB 25	JUL 3	AUG 3	NOV 17	JAN 25	FEB 10	MAR 15	MAY 10	JUN 30	JUL 16	AUG 4	AUG 26	SEP 14	OCT 6	DEC 8
0	8.0	3.6	9.6	2.5	2.0	5.0	3.8	8.0	5.5	5.4	4.8	3.9	1.8	11.0	3.3	4.8
20	8.2	6.1	5.8	3.0	2.0	5.2	2.3	7.9	4.2	0.9	5.0	3.7	2.5	11.4	3.0	4.2
50	7.9	4.4	3.0	4.5	3.1	4.0	5.0	8.0	4.0	0.8	4.3	2.4	1.5	7.5	3.0	4.6
100	8.3	6.2	3.3	3.0	3.3	7.5	4.7	8.0	12.8	1.1	3.8	3.0	2.4	10.0	3.9	8.3
200	16.6	7.3	11.0	11.5	11.0	8.1	11.9	8.2	10.7	1.7	4.8	3.7	10.3	13.5	8.6	14.1
300	20.7	6.6	8.0	3.5	13.1	10.0	19.8	19.3	13.2	2.8	5.0	3.9	15.4	20.1	11.8	16.9
400	18.8	---	14.9	9.5	21.8	19.0	11.4	15.2	14.3	---	5.3	4.1	8.3	17.5	12.3	20.0
BOTTOM (450)	29.4	14.4	16.6	18.5	17.7	15.5	22.0	23.9	14.1	---	4.8	4.1	8.6	35.8	12.3	24.0

Table 14. Total phosphorus (µg/l) at the mid-lake station of Lake Tahoe, 1970-1971.

	1970					1971									
Depth M	Jan 2	Feb 25	Jul 3	Aug 3	Nov 17	Jan 25	Feb 10	May 10	Jun 30	Jul 16	Aug 4	Aug 26	Sep 14	Oct 6	Dec 8
0	2.1	2.3	7.4	8.5	2.6	1.6	5.7	2.1	3.5	5.4	3.5	7.2	9.5	20.4	12.0
20	2.9	7.0	8.3	4.5	2.6	2.4	2.0	2.0	2.3	4.4	3.2	19.5	6.2	21.5	7.1
50	2.1	4.3	6.5	3.5	3.3	3.3	2.9	1.8	1.9	3.5	2.3	2.1	7.5	9.5	7.0
100	4.3	4.4	6.8	5.5	4.6	3.3	10.0	2.1	1.8	3.5	2.4	4.0	14.5	11.3	8.2
200	3.7	4.2	10.7	5.4	3.7	1.8	3.7	1.8	2.3	3.1	2.9	9.5	9.5	8.2	8.2
300	3.0	4.6	11.8	7.0	3.0	1.8	4.8	2.0	4.5	3.5	3.3	2.7	11.5	7.1	16.4
400	3.4	3.8	17.5	6.5	6.9	2.2	2.4	1.7	—	2.4	3.3	2.7	9.0	5.8	13.0
Bottom (450)	3.6	9.2	23.8	0.5	5.0	2.2	2.5	0.9	—	2.5	3.5	24.6	—	12.5	25.2

as nitrate which may reflect a particularly long-term accumulation of organic matter in the deeper waters that could result from a lack of mixing the previous winter.

Silicate-silicon, which may in certain circumstances limit diatom growth, is present in $mg \cdot l^{-1}$ concentrations and does not appear to be greatly influenced by mixing (Table 15). Iron levels are generally low, but some surprisingly high values appear in Table 16.

Oxygen samples collected over a two-and-one-half year period at a mid-lake station indicate Lake Tahoe consistently maintains a high level of oxygen concentration from the surface to bottom (Table 17). The range of all values recorded was within 7-11.6 $mg \cdot l^{-1}$ and percent saturation corrected for altitude always remained above 80%. Slight super-saturation (100-110%) has occurred frequently at depths less than 150 m.

As with temperature (Table 6) seasonal oxygen trends are well-defined and annual surface stratification occurs during the summer, but unlike temperature, the highest values are seldom found at the surface. Lenses of highest oxygen concentration are usually located in or just below the thermocline region from 50 to 100 m during spring and summer months when corresponding surface values are lowest for the year. These maxima are likely to reflect peaks of photosynthetic activity.

These upper-level variations appear to be dependent on both physical and biological factors. Apparently, phytoplankton-zooplankton respiration in combination with higher water temperatures leads to oxygen removal at a rate faster than can be produced photosynthetically. This results in a net oxygen loss in the upper 20-30 m of water from about June to October.

Below 100 meters, the range of yearly variation is less, but still very

TABLE 15. SILICATE-SILICON (mg/l) AT THE MID-LAKE STATION OF LAKE TAHOE, 1971-1972.

	1971					1972
DEPTH M	JAN 25	AUG 26	SEP 14	OCT 6	DEC 8	MAR 15
0	5.2	6.9	5.8	6.4	6.1	5.6
20	3.8	6.6	5.7	6.5	6.4	5.6
50	3.5	6.6	5.8	6.5	6.2	5.6
100	5.0	6.4	5.6	5.6	6.4	5.6
200	5.0	6.7	5.6	8.5	6.4	5.9
300	4.4	6.3	5.6	7.4	6.4	5.8
400	3.4	6.7	5.6	6.5	6.2	5.6
BOTTOM (450)	5.0	7.4	5.8	6.1	6.6	5.7

TABLE 16. IRON (µg/l) AT THE MID-LAKE STATION OF LAKE TAHOE, 1970-1971.

	1970		1971						
DEPTH M	AUG 3	NOV 17	JAN 25	JUN 30	JUL 16	AUG 4	SEP 14*	OCT 6*	DEC 8*
0	8	7	0	6	1	2	13	171	68
20	7	9	28	4	1	1	17	59	5
50	10	6	16	3	1	1	13	21	8
100	12	11	10	4	1	1	20	18	59
200	8	7	126	6	1	1	44	20	10
300	9	7	0	8	1	2	15	8	1
400	14	21	4	-	1	1	13	80	18
BOTTOM (450)	20	46	55	-	1	2	>232	53	38

*HIGH BLANK VALUES.

TABLE 17. OXYGEN (mg/l) AT THE MID-LAKE STATION OF LAKE TAHOE, 1969-1971.

	1969										1970							
DEPTH M	MAR 1	MAY 31	JUL 9	JUL 25	AUG 7	AUG 21	SEP 4	SEP 19	NOV 11	DEC 17	JAN 2	JAN 20	FEB 5	FEB 25	MAR 13	APR 9	MAY 5	JUN 2
0	9.30	8.97	7.83	7.51	7.40	6.85	7.14	8.07	8.38	8.98	9.00	9.07	9.50	10.52	10.49	10.54	10.40	10.00
20	9.27	----	8.99	8.67	8.97	9.34	8.38	7.74	8.44	8.98	9.02	9.06	9.59	10.48	10.52	10.58	10.50	10.54
50	9.26	----	9.40	9.63	9.70	9.94	9.08	10.27	8.51	8.97	9.05	9.06	9.60	10.73	10.55	10.73	10.48	10.91
100	9.24	9.40	9.32	9.22	8.69	9.56	8.63	9.91	9.44	9.17	9.06	9.06	9.52	10.52	10.52	10.48	10.25	10.75
200	9.27	9.25	9.02	8.96	9.14	9.52	8.47	9.65	8.92	9.05	8.82	8.87	9.36	10.44	10.25	10.23	10.03	10.46
300	9.24	9.20	9.00	9.27	8.79	9.55	8.46	9.64	8.96	9.01	8.83	9.01	9.21	10.15	10.10	10.08	9.98	10.20
400	9.23	9.16	8.98	8.83	9.03	9.06	8.40	9.71	8.87	8.93	8.79	8.93	9.59	9.99	9.94	9.80	9.97	10.27
BOTTOM (450)	9.29	9.15	9.00	8.41	8.84	9.29	8.40	9.43	8.73	8.71	8.56	8.64	9.12	9.86	9.90	9.82	9.83	10.08

	1970						1971											
DEPTH M	JUL 3	AUG 3	SEP 9	OCT 16	NOV 17	DEC 30	JAN 25	FEB 10	FEB 24	MAY 10	JUN 3	JUN 30	JUL 16	AUG 4	AUG 26	SEP 14	OCT 6	DEC 8
0	8.98	8.56	8.49	8.30	9.04	9.71	10.31	10.09	11.33	10.50	10.89	10.05	8.42	8.09	8.19	8.22	9.47	9.99
20	10.03	10.48	8.89	8.32	9.05	9.76	10.27	10.06	11.28	10.79	10.93	10.46	9.85	9.67	10.30	9.22	9.53	9.84
50	10.59	11.11	10.68	10.13	9.76	9.76	10.29	9.98	11.33	11.34	11.33	11.56	10.62	11.07	11.12	11.57	11.55	10.25
100	10.54	10.94	10.75	9.86	9.89	9.82	10.28	10.00	11.36	11.09	11.32	11.47	10.44	7.44	10.77	10.85	11.00	10.12
200	10.17	10.60	10.26	9.31	9.39	9.64	10.20	9.63	11.44	10.88	11.27	11.41	10.01	11.24	10.96	10.66	10.81	9.93
300	10.32	10.97	9.90	9.20	9.31	9.39	10.08	9.56	10.98	10.91	11.08	11.02	10.12	10.21	10.45	10.55	10.82	9.90
400	9.92	10.53	9.79	9.04	9.26	9.38	9.93	9.44	10.74	10.82	10.86	----	9.92	9.90	10.31	10.48	10.67	9.72
BOTTOM (450)	9.65	10.05	9.54	9.03	8.96	9.15	9.72	9.43	10.64	11.21	10.66	----	10.11	9.38	10.16	9.51	10.64	9.46

TABLE 18. COMPARATIVE WATER CHEMISTRY (μg/1) OF VARIOUS CREEKS IN THE TAHOE BASIN, 1968.

DATE	NUTRIENT	INCLINE	THIRD	GENERAL	UPPER TRUCKEE	WARD	TAYLOR	EDGEWOOD	MARLETTE	GRIFF	BURKE	FALLEN LEAF	BLACKFOOT	CASCADE	EAGLE	MEEKS	WATSON	BLACKWOOD	GLENBROOK	BLISS	SECRET	TALLAC	MADDEN	NORTH CANYON
10 FEB	NO_3-N	730.0		138.0	25.5																			
	NH_3-N	125.0		125.0	86.5																			
19 FEB	NH_3-N			30.0																				
22 FEB	NH_3-N	34.4																						
25 FEB	NO_3-N	44.0	47.0	38.0	120.0																			
	NH_3-N	33.5	45.6	27.9	67.5																			
	TOTAL P	37.0		19.5	38.3																			
17 MAR	NO_3-N	48.0		36.0	60.0																			
	NH_3-N	42.0	38.0	32.0	36.0																			
	TOTAL P	3.3	2.7	1.5	2.0																			
7 APR	NH_3-N	40.0	41.0	26.0	35.0																			
	TOTAL P	12.8	2.6	3.6	4.6																			
27 APR	TOTAL P	11.0	5.3	2.2	5.3																			
7 MAY	NH_3-N				26.0																			
21 MAY	NH_3-N			17.0																				
28 MAY	NO_3-N	66.0																						
	NH_3-N	15.0																						
	TOTAL P	8.6																						
7 JUN	NO_3-N				32.0																			
	NH_3-N				22.0																			
	TOTAL P				6.6																			
25 JUN	NO_3-N	46.0	30.0					21.0	32.0	36.0	33.0													
	NH_3-N	17.0	23.0					16.0	19.0	21.5	17.0													
	TOTAL P	17.0	12.8					14.3	14.4	8.5	9.2													
27 JUN	NO_3-N			29.0	43.0	26.0						27.0	21.0	25.0	17.0	28.0								
	NH_3-N			13.0	27.0	18.0						19.5	18.0	21.0	20.0	18.0								
	TOTAL P			6.5	5.7	6.3						2.2	4.3	2.2	1.6	2.8								
1 JUL	NO_3-N	29.0	48.0	34.0	47.0	19.0	13.0		22.0	48.0				19.0	28.0	23.0	28.0	24.0	18.0	68.0				
	NH_3-N	19.5	17.0	18.0	20.5	16.0	18.0		17.0	12.0				14.0	18.0	15.0	17.5	15.0	—	20.0				
	TOTAL P	1.6	14.4	8.5	7.6	4.9	3.4		1.6	12.4				3.0	2.7	4.2	11.5	4.4	3.2	19.8				

TABLE 18. CONT'D.

DATE	NUTRIENT	INCLINE	THIRD	GENERAL	UPPER TRUCKEE	WARD	TAYLOR	EDGEWOOD	MARLETTE	GRIFF	BURKE	FALLEN LEAF	BLACKFOOT	CASCADE	EAGLE	MEEK	WATSON	BLACKWOOD	GLENBROOK	BLISS	SECRET	TALLAC	MADDEN	NORTH CANYON
9 JUL	NO_3-N	56.0	55.0	16.0	54.0		17.5	14.0						10.5	12.0	29.0					38.0			
	NH_3-N	53.0	29.0	19.5	19.5		23.0	12.0						23.5	16.0	23.0					20.0			
	TOTAL P	15.8	15.8	8.2	6.7		4.3	15.8						2.5	3.8	6.0					1.5			
16 JUL	NO_3-N	53.0	63.0	14.5	59.0	37.0	17.0	33.0	50.0					12.0	10.0	23.0	17.0	30.0			41.0	17.0		
	NH_3-N	47.0	26.0	17.0	21.0	22.0	15.0	22.0	22.0					14.5	21.5	15.5	17.0	21.0			31.0	28.0		
	TOTAL P	15.5	7.2	7.9	6.7	8.7	3.0	14.8	23.5					2.1	2.6	5.9	6.8	4.6			12.1	3.7		
24 JUL	NO_3-N	48.0	58.0	21.0	53.0	48.0	13.0	31.0	52.0				25.0	16.5	8.0	26.0	16.0				37.0	20.0	40.0	
	NH_3-N	38.0	35.0	19.5	17.0	28.0	21.0	14.0	26.0				19.0	19.0	26.0	20.0	41.0				26.0	23.0	21.0	
	TOTAL P	14.2	10.8	10.7	8.3	10.5	4.0	7.3	15.0				10.2	2.0	2.5	7.5	11.2				9.7	4.7	9.8	
29 JUL	NO_3-N	20.0	11.0	10.5	13.0	22.0	27.0	21.0	21.0				10.0	10.0	67.0	19.0	53.2				10.0	19.0	17.0	
	NH_3-N	43.0	40.0	25.5	25.0	27.0	28.0	25.0	19.0				25.0	17.0	27.0	23.0	32.0				44.0	30.0	26.0	
	TOTAL P	10.8	10.3	4.1	4.0	6.6	2.5	7.4	6.8				3.5	2.2	1.7	6.0	3.8				7.9	4.2	8.0	
5 AUG	NO_3-N	50.0	44.0	85.0	50.0	15.0	84.0	40.0	50.0				9.0	14.5	88.0	14.0	100.0				63.0	33.0	76.0	
	NH_3-N	31.0	29.0	32.0	37.0	33.0	29.0	32.0	32.0				33.0	28.0	33.0	33.0	34.0				32.0	28.0	27.0	
	TOTAL P	16.4	14.4	8.8	17.0	8.9	4.3	14.5	17.2				7.7	2.7	2.7	8.9	6.4				11.8	5.1	5.8	
13 AUG	NO_3-N	56.0	32.0	7.0	49.0	25.0	73.0	41.0	41.0				11.0	22.0	95.0	46.0	62.0				56.0	39.0	86.0	
	NH_3-N	30.0	30.0	26.0	27.0	31.0	32.0	30.0	24.0				27.0	35.0	35.0	29.0	28.0				29.0	31.0	27.0	
	TOTAL P	21.6	17.6	11.7	7.9	10.1	6.0	16.8	20.4				8.5	5.0	4.2	8.1	8.3				14.4	7.3	6.6	
25 AUG	NO_3-N	59.0	30.0	12.0	50.0	16.0	77.0	41.0	36.0				9.0	14.0	59.0	50.0	59.0				58.0	37.0	76.0	42.0
	NH_3-N	34.0	32.0	26.0	35.0	9.0	29.0	36.0	28.0				14.0	30.0	31.0	33.0	20.0				34.0	27.0	26.0	33.0
	TOTAL P	22.4	8.0	10.5	15.1	10.6	6.5	8.5	19.6				8.5	5.3	4.5	9.5	7.5				15.1	8.0	6.6	13.1

much in evidence. The information points to the possibility of large vertical and/or horizontal water mass displacements, but it is difficult to speculate on the significance of this without more knowledge of Lake Tahoe deep water current patterns. Further support of this idea is gathered during periods of vertical mixing and general lake circulation in the fall or early winter and in the spring when the most uniform oxygen values are evident from surface to bottom. On 2 January 1970, the lack of mixing below 200 m is as evident with oxygen as it is with the nitrate already mentioned.

Although spring data are spotty, highest surface oxygen concentrations occur then, but are soon replaced by lower values as the surface temperature increases. It is noteworthy that the deepest samples taken less than one meter from the bottom are always well oxygenated. The lack of reducing conditions anywhere in Tahoe above the mud-water interface has obvious significance in the lack of nutrient re-cycling from sediments that have accumulated in the lake.

Chemistry of Tributaries -

A considerable effort went into measures of nitrate, ammonia, and total phosphorus from the numerous tributaries in Lake Tahoe. The work began in 1968 (Table 18), and continued in 1969 (Table 19), 1970 (Table 20), and 1971 (Table 21). The most obvious result of this sampling is the evidence that streams such as Incline, Third Creek, and the Upper Truckee River carry heavier nutrient loads than those streams such as Ward Creek that drain more natural, undisturbed watersheds. The streams invariably are higher in phosphorus, nitrogen, silicon, and iron than Lake Tahoe, and all contribute to the higher fertility of the inshore waters (see Section IX).

The most polluted stream in the basin is Heavenly Valley Creek (see Section VII). Nitrate-nitrogen values of over $\mu g \cdot l^{-1}$ reflect the former

Table 19. Comparative water chemistry (μg/l) of various creeks in the Tahoe basin, 1969.

Date	Nutrient	Taylor	Ward	General	Upper Truckee	Third	Incline	McKinney
Jun 7	NO_3-N		2.5					
Jun 17	NO_3-N		0.7					
Jun 30	NO_3-N		0.7					
Jul 1	NO_3-N	0.4	0.4	0.9				
Jul 28	Total P		17.0	12.4	19.6		22.2	4.6
	NO_3-N		<1.0	0.2	2.3		0.7	3.8
Aug 11	Total P	3.9	18.9	18.9	19.6	54.0	43.0	5.9
	NO_3-N	2.0	<1.0	0.2	2.3	<1.0	0.2	3.6
Sep 1	Total P	4.9	16.0	21.5	19.6		39.0	19.6
	NO_3-N	14.0	2.7	1.8	2.8		5.6	33.0
Sep 15	Total P	9.2	19.6	32.0	22.3	36.5	62.2[1]	10.5
	NO_3-N	18.2	0.8	1.6	12.6	3.4	4.7[1]	11.9
Oct 17	Total P			27.0		84.0	99.0	
	NO_3-N			2.3		8.6	7.0	
Nov 25	Total P			29.0		17.3		
	NO_3-N			2.9		4.3	258.0	
Dec 20[2]	Total P			28.0		320.0	93.0	
	NO_3-N			218.0		291.0	258.0	

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[1] Sampled Sept 17, 1969

[2] Rain storm samples

TABLE 20. COMPARATIVE WATER CHEMISTRY (μg/l) OF VARIOUS CREEKS IN THE TAHOE BASIN, 1970.

Date	Constituent	Ward	General	Taylor	Upper Truckee	Trout	Incline	Third	Heavenly	Heavenly & Trout	McKinney	Blackwood	Truckee	Burton	Polaris	Watson	Cascade	Eagle	Meeks	Madden	Glenbrook	Zephyr Cove	Second	Tallac	Mill
8 Jan	Total P			5.5																					
	NO_3-N			27.1																					
20 Jan	Total P	13.5	2.5				65.8	28.2			6.9	32.4													
	NO_3-N	65.5	28.6				123.0	189.0			100.2	189.0													
25 Mar	Total P	7.0	< 5.0				80.0	150.0																	
	NO_3-N	< 5.0	5.0				18.5	7.0																	
17 Apr	Total P	7.0	< 5.0	< 5.0	6.0	34.0																			
	NO_3-N	6.5	7.5	7.0	22.0	78.0																			
24 Apr	Total P	33.0					34.0	34.0																	
	NO_3-N	26.5					30.5	17.0																	
25 Apr	Total P						62.3	41.8																	
	NO_3-N						28.4	5.5																	
6 May	Total P								41.1	16.9															
	NO_3-N								911.0	98.0															
7 May	Total P	10.0	<5.0	< 5.0		18.5	32.0	35.0																	
	NO_3-N	16.5	7.5	9.0		36.5	45.0	45.0																	
21 May	Total P	3.3	13.1	21.5		4.6	11.7	11.7	55.2	8.8	0.3	12.4	5.2	5.2	11.1	2.0	1.6	1.3	1.0	3.3					2.6
	NO_3-N	11.1	1.4	5.6		6.3	15.6	6.1	25.5	7.2	7.0	8.8		0.9	3.2	1.6	0.7	2.9	1.6	4.1					0.4
22 May	NO_3-N	15.0	5.0		24.0		33.0	34.0																	
5 Jun	Total P		7.5		9.5		20.2	33.4	66.0																
	NO_3-N		28.5		20.5		54.0	50.0	333.0																
	Fe		36.		88.		234.	516.	675.																
14 Jun	Total P	5.0																							
	NO_3-N	10.5																							
28 Jun*	Total P	10.0	8.8	6.4	15.8	35.5	41.5	35.0																	
	NO_3-N	36.0	35.0	33.0	19.0	[illegible]	150.0	40.0																	
	Fe	30.	42.	22.	207.	394.	502.	300.																	
28 Jun*	Total P	6.0																							
	NO_3-N	9.5																							
6 Jul	Total P		11.0	< 5.0	10.0	18.5	51.0	21.5																	
	NO_3-N		13.5	24.5	25.0	36.5	17.0	20.0																	

TABLE 20. CONT'D.

Date	Nutrient	Ward	General	Taylor	Upper Truckee	Trout	Incline	Third	Heavenly	Heavenly & Trout	McKinney	Blackwood	Truckee	Burton	Polaris	Watson	Cascade	Eagle	Meeks	Madden	Glenbrook	Zephyr Cove	Second	Tallac	Mill
13 Jul*	Total P	8.0	7.2	4.0	72.8	8.9	17.4	24.2	9.4		2.6	6.6	62.2	8.0	26.9	5.9	3.1	2.7	4.6	6.0	17.0	8.0	28.5		
	NO_3-N	9.2	4.5	18.3	25.1	28.3	12.3	13.7	113.6		68.4	3.8	0.5	8.1	18.2	28.6	2.7	25.1	10.5	13.3	79.8	6.0	8.1		
	Fe	17.	9.	15.	130.	85.	107.	68.	290.		20.	12.	8.	10.	13.	40.	30.	15.	16.	36.	45.	18.	306.		
13 Jul*	Total P	12.5	12.5	5.0	9.0	18.5	46.0	26.0																	
	NO_3-N	9.5	12.5	19.5	37.4	31.8	24.0	21.0																	
22 Jul	Total P	8.0	19.0	5.0	12.0	18.0	54.0	30.0																	
	NO_3-N	14.2	20.0	27.9	47.3	40.5	39.5	54.3																	
28 Jul	Total P	14.0	16.0	5.0	7.0	13.0	95.0	44.0																	
	NO_3-N	11.0	11.0	31.0	55.0	49.0	28.0	220.0																	
4 Aug	Total P	18.5	23.0	7.5	9.0	16.0	50.5	107.0	12.0		3.0	7.5	3.5	8.0	67.0	20.0	4.0	4.0	3.5	9.5	50.5		53.0	3.5	
	NO_3-N	13.0	5.5	33.5	34.5	15.5	15.0	186.0	400.0		48.5	6.5	5.0	13.5	30.5	59.0	9.0	42.5	14.5	18.0	58.5	6.0	12.5	36.5	
	Fe	10.	9.	18.	145.	97.	131.	75.	380.		18.	14.	9.	10.	16.	45.	36.	22.	21.	44.	44.		380.	12.	
5 Aug	Total P	19.0	45.0	26.5	36.0	42.5	46.5	66.5																	
	NO_3-N	11.5	8.7	37.0	45.0	65.5	28.0	38.0																	
12 Aug	Total P	20.0	18.0	5.0	8.0	16.0	22.0	43.5																	
	NO_3-N	13.0	8.0	25.5	53.0	45.0	26.0	56.0																	
26 Aug	Total P	37.5	38.5			44.5																			
	NO_3-N	5.5	5.0			27.5																			
8 Sep	Total P		38.5	25.0	35.0	40.0	62.5	98.5																	
	NO_3-N		5.0	7.0	72.0	31.5	85.0	350.0																	
17 Sep	Total P	43.0	48.5	27.5	35.0	42.0	54.5	120.0																	
	NO_3-N	28.0	13.0		88.0	57.0	50.0	2220.0																	
23 Sep	Total P	18.0	20.0	5.0	11.5	18.0	27.0	30.0																	
	NO_3-N	7.0	8.7	27.0	50.5	21.5	29.5	58.5																	
23 Oct	Total P		53.0	30.0	30.5	44.5																			
	NO_3-N		5.0	30.0	48.5	15.0																			
6 Nov	Total P		11.5	8.1	21.2	15.4	26.7	20.3					4.8												
	NO_3-N		4.6	40.7	159.5	48.1	32.0	29.0					5.2												
	Fe		37.	24.	106.	115.	108.	139.					140.												
10 Dec	Total P	25.0	20.0	30.0	35.0		63.5	38.0																	
	NO_3-N	25.0	21.0	12.5	69.0		65.0	34.5																	

* Sampled on the same date at different times of the day.

TABLE 21. COMPARATIVE WATER CHEMISTRY (μg/l) OF VARIOUS CREEKS IN THE TAHOE BASIN, 1971.

Date	Nutrient	Ward	General	Taylor	Upper Truckee	Trout	Incline	Third	Heavenly	McKinney	Zephyr	Tahoe Vista	Polaris	Second	Burton	Truckee
2 Jan	Total P	7.7	11.6	8.1	3.9	7.2	21.9	19.4	26.9	3.2	7.3		34.8	66.0	6.4	2.5
	NO_3-N	23.8	16.9	31.6	76.2	101.5	76.2	59.0	1257.9	62.4	11.2		56.0	64.4	23.8	5.5
	Fe	0.	126.	1.	80.	187.	155.	149.	80.	46.	126.		14.	152.	50.	68.
21 Jan	Total P	31.5	33.0	43.5	43.0	52.0	75.0	54.5								
	NO_3-N	31.0	12.0	10.5	42.0	83.0	107.0	50.0								
28 Jan	Total P		34.5	33.0	37.0	50.0										
	NO_3-N		10.5	14.0	85.0	99.0										
4 Feb	Total P	42.0	36.0	33.0	37.0	46.5	69.5	47.0								
	NO_3-N	13.0	18.5	25.5	55.0	81.0	97.0	40.0								
20 Feb	Total P		5.0	5.0	6.0	10.0	29.5	35.0								
	NO_3-N	13.0	6.0	18.0	66.0	76.5	88.0	52.0								
4 Mar	Total P	6.0	< 5.0	5.0	7.5	14.0	20.5	15.5								
	NO_3-N	18.0	12.5	42.5	82.0	91.0	73.0	46.0								
28 Mar	Total P	5.7	3.3	3.9	9.3	4.6	84.2	53.9	5.5	11.8	10.4	31.6	60.8	22.8	6.2	0.0
	NO_3-N	25.7	14.7	6.9	109.8	136.0	106.7	91.9	1071.0	61.2	18.0	492.3	146.0	29.8	40.2	6.1
	Fe	32.	31.	16.	194.	142.	153.	172.	148.	53.	92.	169.	177.	167.	163.	46.
1 Apr	Total P	5.5	< 5.0	< 5.0	5.5	12.5	74.8	39.0								
	NO_3-N	32.5	14.0	11.0	102.0	127.0	118.0	102.0								
22 Apr	Total P	< 5.0	< 5.0	< 5.0	5.5	6.0	20.2	23.0								
	NO_3-N	12.5	40.0	8.0	66.0	102.0	78.0	42.0								
4 May*	Total P	2.2	2.6	1.2	2.9	7.8	113.7	176.5	19.6	5.1	4.5	15.6	22.6	257.6	6.6	0.3
	NO_3-N	14.2	12.6	6.5	35.5	57.3	86.3	71.4	1155.6	64.5	15.3	171.9	15.8	12.3	6.3	4.1
	Fe	18.	17.	12.	241.	232.	72.	216.	229.	251.	184.	75.	24.	88.	176.	5.
4 May*	Total P	< 5.0	< 5.0	< 5.0	< 5.0	11.0	51.7	61.5								
	NO_3-N	25.5	29.2	14.5	38.0	71.0	82.0	70.0								
20 May	Total P	< 5.0	< 5.0	< 5.0	16.5	21.5	24.5	23.0								
	NO_3-N	23.5	6.0	9.5	25.0	40.0	64.0	39.0								
3 Jun	Total P		< 5.0	< 5.0	5.5	19.5	24.0	9.0								
	NO_3-N		8.0	8.0	24.5	35.5	46.5	28.0								
6 Jul	Total P	6.1	2.2	4.9	16.8	24.4	20.3	6.4	29.6	39.8	8.2	3.2	21.0	5.2	4.3	2.5
	NO_3-N	4.5	5.2	7.3	11.7	25.2	13.2	5.5	120.0	20.0	4.1	2.9	25.2	3.6	3.2	1.9
	Fe	21.	16.	14.	48.	54.	90.	22.	83.	54.	22.	18.	56.	22.	16.	15.
6 Aug	Total P	6.1	1.5	5.2	13.6	21.2	19.7	10.1	30.8	27.1	5.2	3.7	16.4	4.5	3.7	2.4
	NO_3-N	3.6	4.1	5.9	12.3	18.0	12.1	3.0	92.8	10.7	4.6	3.0	26.2	4.6	3.9	3.7
	Fe	6.	4.	11.	30.	15.	27.	24.	15.	9.	8.	6.	27.	11.	5.	5.
3 Sep	Total P	19.0	21.0	6.5	9.0	30.1	36.2	56.4	32.5	5.4		40.5	94.5	46.8	17.5	17.8
	NO_3-N	6.5	5.3	22.0	39.2	19.0	30.5	31.5	~1900.0	89.5		4.0	34.5	9.5	7.0	5.3
	Fe	6.	31.	18.	75.	89.	98.	102.	104.	22.		70.	28.	120.	34.	73.
	SiO_2-Si (ppm)	7.4	10.1	2.4	8.0	7.2	9.2	7.[illegible]	7.6	7.5		10.8	16.1	9.9	14.8	6.1
18 Nov	Total P	27.0	23.5	31.0	43.5	37.5	33.5	41.5		16.5			90.5	218.0	24.8	12.0
	NO_3-N	31.5	6.5	36.2	63.2	49.4	23.4	11.0		62.0			28.7	15.2	11.4	6.5
	Fe	8.	22.	50.	132.	232.	54.	66.		60.			28.	175.	62.	17.
	SiO_2-Si (ppm)	11.7	11.7	1.8	4.2	8.4	11.9	9.7		6.9			17.0	9.2	13.5	5.8
18 Dec	Total P	16.1	17.0	19.7	14.3	8.0	24.4	19.0		9.7		29.2	134.0	96.4	11.8	7.2
	NO_3-N	57.0	26.6	16.6	92.5	65.0	58.0	10.6		81.5		15.3	39.6	35.7	11.0	5.6
	SiO_2-Si (ppm)	12.0	9.2	1.7	8.0	8.5	11.2	9.0		6.6		14.0	15.3	10.6	13.1	5.8

*SAMPLED ON SAME DATE AT DIFFERENT TIMES OF DAY AND DIFFERENT LOCATION IN THE CREEK.

TABLE 21. CONT'D.

DATE	WATSON	TAHOE CITY	GLENBROOK	BLACKWOOD	CASCADE	EDGEWOOD	MILL	MEEKS	EAGLE	MADDEN	COLD	SLAUGHTER HOUSE	SECRET HARBOR	CARNELIAN BAY	FIRST	INCLINE
2 JAN	3.0	6.7	11.9	4.7				4.8				18.7				3.3
	71.3	83.3	27.6	18.6				20.8				72.3				68.5
	29.	112.	154.	102.				121.				159.				38.
21 JAN																
28 JAN																
4 FEB																
20 FEB																
4 MAR																
28 MAR	4.0	6.2	19.4	5.8	1.3		87.5	12.8	3.3		10.8					
	68.4	58.4	255.3	82.2	13.3		155.0	13.7	39.5		63.3					
	64.	124.	179.	163.	15.		167.	100.	37.		174.					
1 APR																
22 APR																
4 MAY*	2.5	8.9	14.9	1.7	0.8		98.3	1.3	0.9	2.9		20.3	6.7	13.0	46.9	
	62.7	79.2	209.0	78.4	3.5		51.7	12.3	37.9	80.4		65.6	48.6	31.7	40.3	
	31.	96.	192.	65.	17.		216.	30.	40.	20.		230.	219.	214.	180.	
4 MAY*																
20 MAY																
3 JUN																
6 JUL	8.5	58.6	21.4	36.4	6.1		9.4	6.1	8.1	3.1	4.3					
	6.5	292.0	63.8	28.7	3.2		12.4	11.8	9.2	4.4	1.8					
	45.	97.	46.	40.	10.		47.	19.	27.	12.	20.					
6 AUG	9.5	33.0	15.6	31.3	5.1	3.8						6.9				
	7.2	194.8	45.8	22.2	3.9	3.2						7.2				
	11.	43.	9.	6.	11.	7.						8.				
3 SEP	17.2	62.4	~ 360.0	13.3	4.6	44.6		30.1	4.2		37.5	65.0				
	43.5	24.0	13.0	5.5	11.6	22.0		7.0	66.0		14.0	75.0				
	32.	82.	102.	32.	4.	80.		76.	5.		94.	100.				
	12.4	11.6	5.8	11.9	0.4	6.8		4.2	0.5		6.1	6.1				
18 NOV	11.5		31.0	27.0												
			38.0	11.0												
	40.		111.	42.												
	10.4		9.8	12.2												
18 DEC			12.1	8.3				12.0	5.4	10.6						
			110.0	28.3				36.3	36.6	164.5						
			9.9	11.8				5.6	1.7	9.9						

*SAMPLED ON SAME DATE AT DIFFERENT TIMES OF DAY AND DIFFERENT LOCATION IN THE CREEK.

use of its watershed for land disposal of treated sewage from the South Tahoe treatment plant. The water from this drainage was detectable well out into the lake (Goldman and Armstrong 1969).

Transects along the course of two creeks in the disturbed Incline area were also included during the 1969 program (Table 22). The increase in both nitrate and phosphorus as one proceeds downstream towards the mouth is particularly evident in Incline Creek. Third Creek showed high mid-course values during the 24 November 1969 sampling.

TABLE 22. WATER CHEMISTRY (µg/l) OF INCLINE AND THIRD CREEK TRANSECTS, 1969.

INCLINE CREEK TRANSECT

DATE	NUTRIENT	MOUTH	INCLINE WEST	TAHOE BLVD.	COUNTRY CLUB DRIVE	FAIRVIEW BLVD.	ABOVE SKI INCLINE	SKI INCLINE	BELOW SKI INCLINE	ABOVE TYROLEAN VILLAGE	TYROLEAN VILLAGE	BELOW GOLF COURSE
17 SEP	TOTAL P	62.2	52.0	51.0	23.7	28.6		37.7		31.5	45.4	
	NO_3-N	4.7	4.6	4.2	3.8	3.1		1.8		0.8	1.6	
17 OCT	TOTAL P	99.0							64.0			69.0
	NO_3-N	7.0							6.0			6.0
25 NOV	NO_3-N	258.0					189.0					

THIRD CREEK TRANSECT

DATE	NUTRIENT	MOUTH	BELOW GOLF COURSE	ABOVE GOLF COURSE	EAST FORK	ABOVE MT. ROSE HWY.	MT. ROSE HWY.	HEADWATERS (8000')
17 OCT	TOTAL P	84.0	64.0			27.0		
	NO_3-N	8.6	12.6			7.2		
25 NOV	TOTAL P	17.3	9.5	34.0	69.0		36.0	17.6
	NO_3-N	4.3	4.7	7.0	26.0		4.3	4.5
20 DEC*	TOTAL P	320.0					66.0	
	NO_3-N	291.0					147.0	

*RAINSTORM SAMPLES

SECTION VI

PHYTOPLANKTON PRIMARY PRODUCTIVITY, SPECIES COMPOSITION AND ABUNDANCE

PRIMARY PRODUCTIVITY

Introduction

The general emphasis in this study on measurement of primary productivity is based on the idea that rates of carbon fixation are a sensitive indicator of eutrophication. The primary producers forming the base of the food chain in the Tahoe ecosystem provide the best integration of the complexity of physical, chemical, and biological indicators of eutrophication and are the most sensitive indication of change in the system known to the principal investigator.

Primary productivity was measured with the ^{14}C method at the index station for detection of the seasonal and long term trends. A synoptic approach was used for determining the degree of areal variation and productivity transects were run offshore for studies of the potential as well as the immediate influence of certain disturbed and undisturbed tributaries on near shore fertility. Tahoe is unusual among the lakes of the world in having a euphotic zone that extends to at least 100 m with one or two maxima occurring at great depths. The evolution of the vertical profile of productivity in this remarkably clear lake has been an area of considerable investigation as has the trend of increasing productivity over the four and one half years of study. The question of degree and rate of eutrophication in Tahoe has been the subject of both national and international concern. Considerable attention is therefore given to this problem in the analyses of the results of this portion of the investigation. The trend towards higher rates of carbon fixation is very clear from the results presented here.

Methods

Measurements of primary productivity were made *in situ* with the ^{14}C method of Steemann Nielsen (1952) using the modifications of Goldman (1963).

Samples taken at the index station (Figure 1) near the western shore of Lake Tahoe, were collected weekly or tri-monthly depending on weather conditions and personnel availability. From 28 July 1967 through 28 September 1967 samples were taken from depths at which "standard" percentages of surface light ("total" light) was transmitted. These corresponded to the depths at which 100%, 75%, 50%, 25%, 10%, 5%, and 1% of the surface light was transmitted. It was soon realized that: 1) sampling at irregular depths (meters) was a great inconveniance overall, 2) significant amounts of primary productivity could still be measured below the depth of the 1% light transmission, and 3) greater density of measurements was needed in the region of greatest rate of change of primary productivity with depth. The sampling was extended first to ten fixed depths between 0 and 90 m, then to twelve depths between 0 and 90 m on 1 November 1967. The euphotic zone was found, however, to extend even beyond 90 m depths at certain times of the year. The depth of 105 m was added on 1 May 1968 to the regular sampling program at the index station. Since then, thirteen depths were sampled: 0, 2, 5, 10, 15, 20, 30, 40, 50, 60, 75, 90, and 105 m. A completely opaque PVC Van Dorn bottle was used to take each sample of water from which subsamples for primary productivity and other measurements were collected. Particular care was taken not to expose the samples to surface light by filling each of the 13 duplicate 125 ml light glass bottles in a dark container and keeping them in the dark during collection time. A dark bottle was also included for each depth as a measure of non-photosynthetic carbon uptake. These were painted white to avoid direct heating from solar radiation. Rapid addition of ^{14}C sodium carbonate solution from 20 ml glass ampoules was made with an automatic syringe of 1 ml capacity calibrated by weight to deliver 0.50 ml to the glass stoppered 125 ml bottles. In situ incubation of light and dark bottles was from 1000 until 1400 hours. Immediately after incubation the samples were transported to the lakeside laboratory in insulated light proof containers and filtered through HA Millipore^{R} filters (0.45 ± 0.02 μm pore size) of 30 mm diameter. The filtration was done at low (10-15 mm Hg) vacuum within half an hour after the end of the in situ exposure. Filters were air dried at least 24 hours.

Radioactivity measurements of filters were performed with an automatic Nuclear Chicago D-47 gas flow counter (Nuclear Chicago Corp., Des Moines, Ill., U.S.A.) equipped with an ultrathin micromil® window. To eliminate serious errors in calibration and counting, the efficiency of counting was determined by gas phase analysis (Goldman 1968a). The absolute activity of the ^{14}C sodium carbonate solution used was measured by the same method and was 4 to 5 μC per ml.

The total inorganic carbon content of the water was measured at each depth from a subsample taken from the same Van Dorn sample as the ^{14}C sample. Initially inorganic carbon was determined through measurement of pH, temperature, and alkalinity by standard acid titration techniques (American Public Health Association 1965) and conversion using the table of Saunders, Trama and Bachmann (1962). After July 1969, the inorganic

C^{12} available for photosynthesis was measured by means of a Beckman® IR-215A infrared analyzer.

The results of the measurements were recorded on IBM data cards, in a format to fit the standard computer program developed by the limnology group at the University of California at Davis to compute all the primary productivity measurements made with the methods described above. This program computes the mg of carbon fixed per cubic meter per hour of incubation at each sampled depth, the mg of carbon fixed per hour of experiment in the entire column of water under a square meter, the mg of carbon fixed per day per cubic meter, and per day per square meter of surface. In addition, the mg of carbon fixed under a square meter in the entire column of water per calorie of light available at the surface of the lake was computed. The program contains several other optional features that were not used in the present study. An IBM 7044 and later a Burroughs 6700 computer were used for data processing. The Burroughs 6700 together with a Calcomp Digital Incremental Plotter Model 563 were used for graphing Figures 18 and 19.

Other measurements taken at the index station in parallel with the primary productivity included light, Secchi depth, and temperature. Water chemistry samples were taken at each depth from the same Van Dorn sample whenever possible. Phytoplankton was also collected from the same Van Dorn sample as primary productivity. Zooplankton samples were taken in triplicate with a 150 m to 0 m vertical haul. For a specific description and discussion of these measurements refer to Sections IV, V, VI for phytoplankton and Section X for zooplankton.

Results and Discussion

Results of primary productivity measurements are given in Appendix B The values of total primary productivity under a square meter surface for the day are shown in Figure 18. They vary between 42 mg $C \cdot m^{-2} \cdot day^{-1}$ on 25 April 1968 and 259 mg $C \cdot m^{-2} \cdot day^{-1}$ on 24 August 1971. The low value of 25 April 1968 is due in part to some depths at which carbon fixation in the dark bottle was higher than in the light bottle. Estimates of experimental error in integral photosynthesis have been given and discussed by Goldman and Carter (1965). The mean value of primary productivity per cubic meter of water of the euphotic zone varies correspondingly between 0.5 mg $C \cdot m^{-3} \cdot day^{-1}$ and 2.6 mg $C \cdot m^{-3} \cdot day^{-1}$. These values place Lake Tahoe among the most oligotrophic lakes of the world. It is only slightly more productive than the permanently frozen Lake Vanda in Antarctica (Goldman 1968b).

Primary productivity-depth curves are shown in Figure 19. This figure shows the results from measurements of about 6,200 samples taken from 28 July 1967 to 16 December 1971. Units are in milligrams of carbon per cubic meter per hour of incubation time. This represents the mean productivity per hour between approximately 10 a.m. and 2 p.m. on the day that the samples were taken and incubated. Although primary productivity was measured to a depth of 100 m, it is apparent on some days primary productivity would have been found to be significantly greater than zero at even greater depths. The euphotic zone (where net photosynthesis occurs) extends to at least 100 m depth for Lake Tahoe. It is due in part to the remarkable transparency of the Lake Tahoe water, which allows light to penetrate deeper than in most of the world's lakes and in part to the ability of Lake Tahoe deep water phytoplankton to efficiently utilize extremely low light intensity for photosynthesis. The depth at which one percent of the light received on the surface of a lake is transmitted is generally considered to be the depth of the euphotic zone. This is often not the case in Lake Tahoe where values of primary productivity significantly greater than zero are recorded much below the depth of one percent light transmission. Some examples of this for 1969 are presented in Figure 20. On 23 May, in particular,

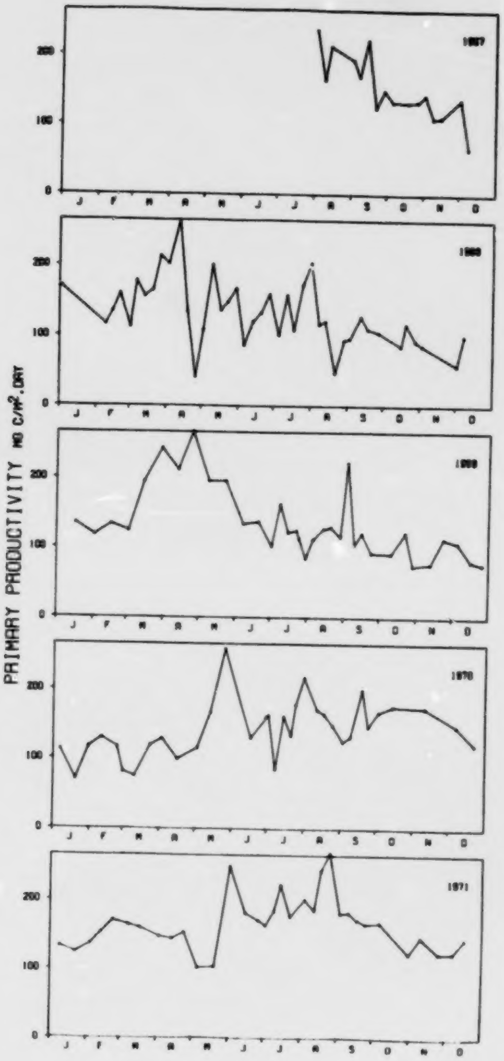

Figure 18. Total primary productivity at the index station of Lake Tahoe from mid-1967 through 1971.

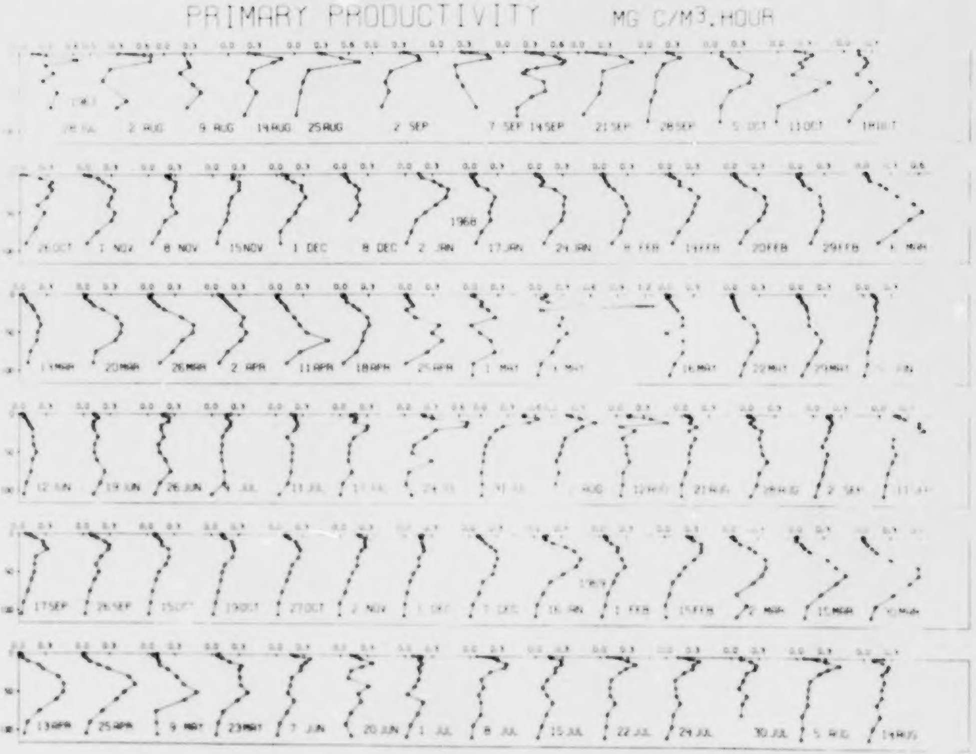

Figure 19a. Primary productivity-depth curves at the index station of Lake Tahoe from mid-1967 through 1971.

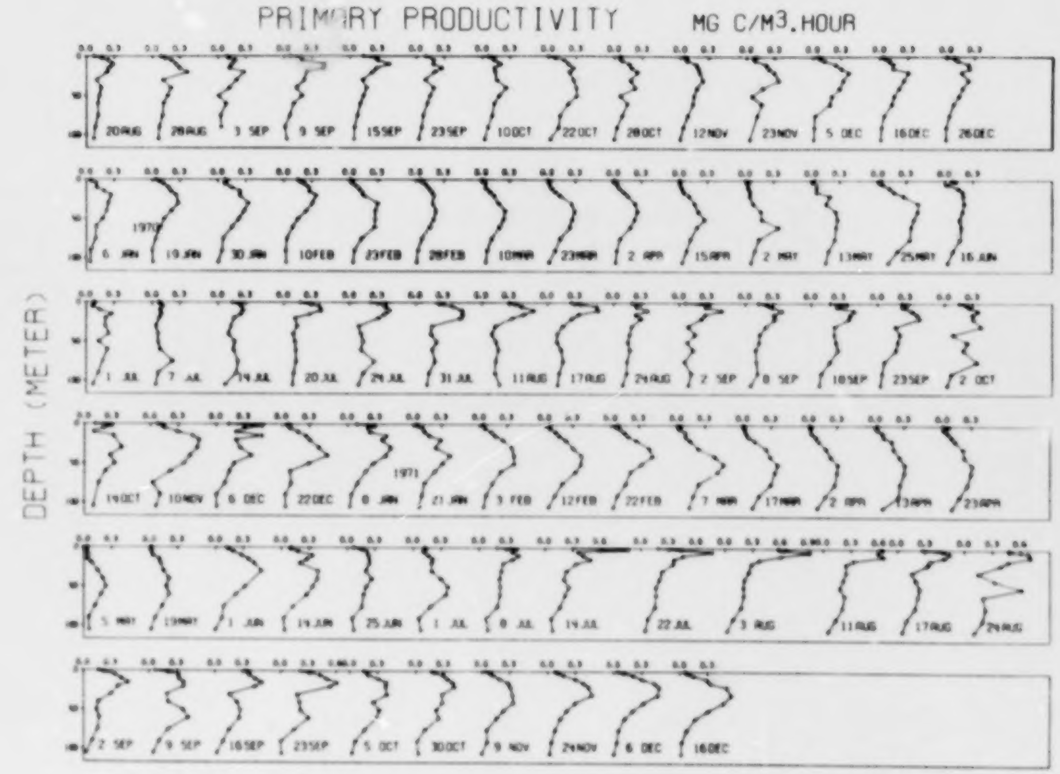

Figure 19b. Primary productivity-depth curves at the index station of Lake Tahoe from mid-1967 through 1971.

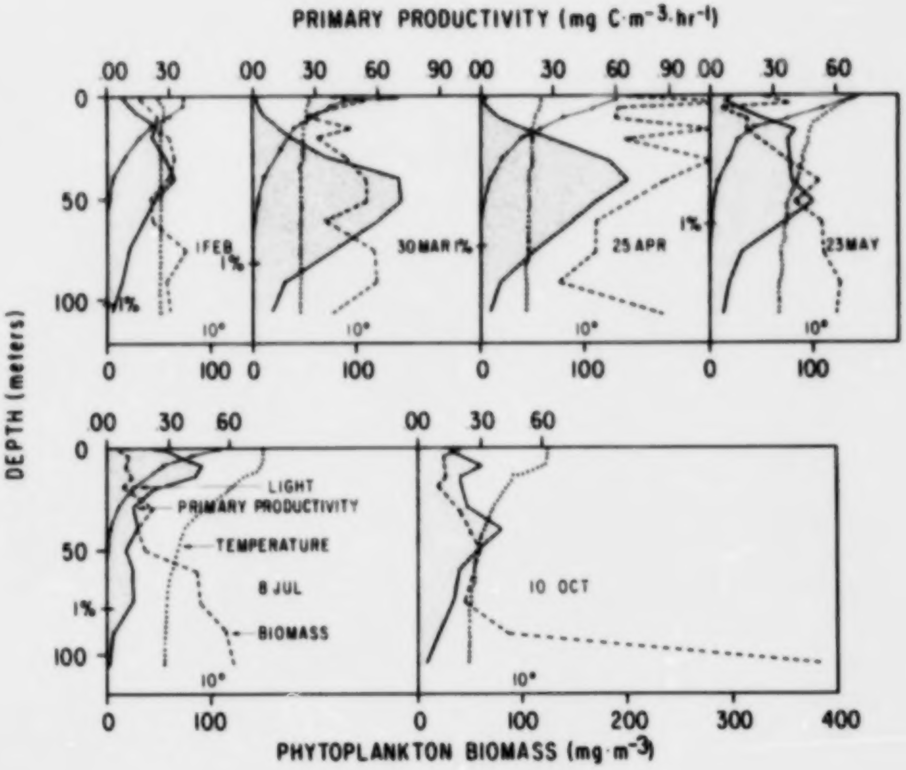

Figure 20. Representative vertical profiles of primary productivity, temperature, light, and phytoplankton biomass at the index station of Lake Tahoe in 1969.

one percent light was recorded at 60 m with a euphotic zone greater than 105 m. On that day the maximum primary productivity of 0.40 mg $C \cdot m^{-3}$ per hour (and 3.54 mg $C \cdot m^{-3} \cdot day^{-1}$) occurred at 50 m. Only 2.4 percent of the surface light reached that depth! This represents 8.28 langleys of light (gm $cal \cdot cm^{-2}$) available for photosynthesis at 50 m that day, and a photosynthetic efficiency of 0.41 mg $C \cdot m^{-3} \cdot ly^{-1}$. Similarly on 30 March 1969, at 1% light transmission there were 2.7 langleys of light available for photosynthesis which gives an efficiency of utilization of 0.86 mg $C \cdot m^{-3} \cdot ly^{-1}$. These values of efficiency are similar to those measured in Castle Lake, California (Goldman 1970b) where the depth of the euphotic zone is only 30 m.

Maxima of primary productivity in Lake Tahoe are found at remarkably great depths at times, as compared with other lakes. These correspond quite often to times of high seasonal productivity. These deep maxima are commonly found at 50 or 60 m, but occasionally as deep as 75 m (Fig. 19 and Fig. 20). On 1 May, 19 June, and 26 June 1968 a maximum occurred at 75 m.

The study of four and a half years of data, collected regularly with relatively short intervals of time between sampling, made apparent an extremely interesting pattern of seasonal change in the shape of the primary productivity-depth curves, or "profile" of primary productivity. Lake Tahoe productivity has two different, typical, profiles depending on the time of the year. In winter and spring it is a unimodal curve with one maximum. This single maximum appears near the surface of the lake, sometimes in December, while there is very little light and overall primary productivity values are low. The maximum slowly descends deeper into the lake as solar radiation increases and overall primary productivity values increase. During this period the lake is homothermal. The highest value of this maximum is reached at the very end of the winter or in the first half of spring at 50 m or 60 m depth. It remains at that depth or sinks another 10 or 15 m until May or early Juen when surface water temperatures increase significantly and stratification sets in. At that time the simple curve of primary productivity that had persisted through the last five or six months gives way to a curve with two maxima. The two maxima appear first rather close together in the upper part of the water column. The upper maximum remains in the first 20 m of water until November,while the second maximum remains below 30 m and as already noted may occur as deep as 75 m. These depths correspond to regions in the hypolimnion for the "deep" maximum and in the epilimnion or in the vicinity of the discontinuity layer for the upper maximum. This two-maxima shaped curve of primary productivity and its relation to the thermocline is not unfamiliar in lakes and has been previously described for Castle Lake (Goldman, Stull, and Amezaga 1973). As the surface water cools off in the fall and the upper 30 or 40 m of water becomes homothermal, more than two maxima might occur temporarily. The lower maxima will eventually disappear as the light intensity declines in fall and winter and the simple shaped, one maximum, curve returns.

The upper 100 m characteristically undergoes gradual nitrogen depletion during the spring and summer months. Although most index station sampling was restricted to the upper 105 m (Table 9), deep water sampling in 1969 and 1971 (Table 13) shows higher levels rather consistently below 100 m. Paerl et al. 1974 have clearly demonstrated the importance of winter mixing in 1973 to redistribution of the limited nitrate supply. Further, the phytoplankton clearly reduce the nitrate level in the euphotic zone.

Extremely low values of photosynthetic carbon fixation, a remarkably deep euphotic zone with deep maximum, and the seasonal change in the profile are all characteristics of the primary productivity of Lake Tahoe that have prevailed through the course of the study; the preceeding work as well as the ongoing research program.

Careful examination of several consecutive years of measurements at Lake Tahoe point out, however, other characteristics that may be indicative of how long this particular stage in the life of the lake might be. These characterize the long term trends of primary productivity that only become apparent when we compare the total primary productivity of one year with the next, and the relative time of occurrence of seasonal maxima or minima.

The monthly total of primary productivity and the yearly total primary productivity were calculated for each year from the values of primary productivity per day under a square meter of lake surface (Fig. 21). These values were obtained by mathematical integration under the seasonal curve shown in Figure 18 per month and per year. Verification of these computer results was done by comparison with values obtained by hand with planimetry of the area under the same curves. The results indicate that there has been a steady increase in the primary productivity of Lake Tahoe from year to year over the four years of most intensive study (Table 23).

Table 23

Total primary productivity per year under a square meter surface at the Lake Tahoe index station.

Year	$mg \cdot C \cdot m^{-2} \cdot year^{-1}$	Percent increase over the previous year
1959-60	38,958	
1968	46,685	20% since 1959-60
1969	50,525	8.23%
1970	52,467	3.84%
1971	58,655	11.79%

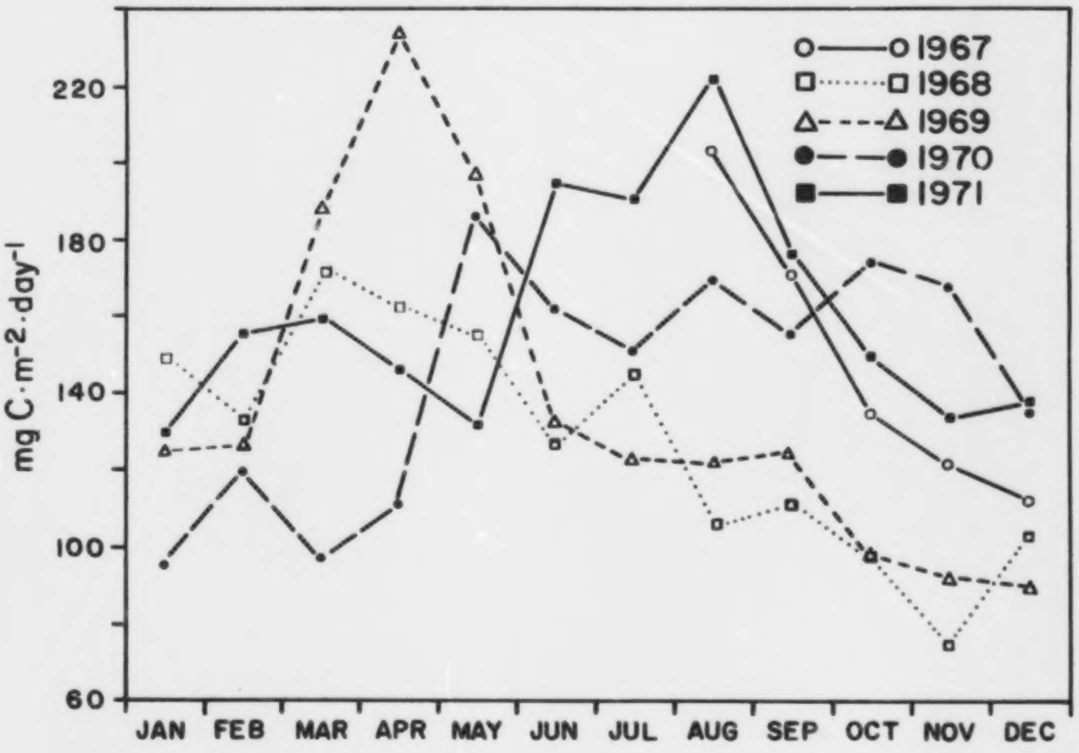

Figure 21. Seasonal total primary productivity at the index station of Lake Tahoe from mid-1967 through 1971. Each point is the average for the month.

The difference between the 1971 and the 1968 values represents an increase of 25.6 percent in total primary productivity at the index station over a period of only four years.

Earlier measurements of primary productivity have been made since 1959 as part of a series of northern California lake studies (Goldman 1964) The data collected monthly off Cave Rock (Fig. 1) between 4 June 1959 and 31 May 1960 were used for comparison with total annual productivity of the recent years. Any value of mg $C \cdot m^{-2} \cdot day^{-1}$, that seemed to have been an underestimate of the primary productivity for the day (if the deepest sampling depth measured was above the depth of the euphotic zone), was increased accordingly by assuming the compensation depth to be at 100 m. This assumption was based on observations of the vertical curves of primary productivity of the years 1968 through 1971 as reported above. These results were graphed and the area under the curve was planimetered to give a comparative value of total annual primary productivity for the year 1959-60. From 1968 through 1971 simultaneous measurements of primary productivity were made at the index station and off Cave Rock on thirteen different dates. The averages of these measurements from these two widely separated stations gave a ratio of 0.9933. On this basis of less than 1% difference in the two stations, the 1959-60 Cave Rock data is included in the plot of the change in productivity at Lake Tahoe from 1959 through 1971. This value was 35,326 mg $C \cdot m^{-2} \cdot year^{-1}$ which would indicate an increase of about 32% from 1959-60 to 1968 and an increase of 66% from 1959-60 to 1971! Two of the single monthly measurements for 1959-60 indicated no measurable primary productivity at all, due to very stormy conditions and very low light intensity on these two days. To use a more representative monthly value of primary productivity for these two months the zero value was replaced by a three point average using the value of the measurement before and the measurement following the particular day.

The total primary productivity per square meter for the year was recalculated and found to be a conservatively high value of 42,590 mg $C \cdot m^{-2} \cdot year^{-1}$. The mean of the low estimate and the high estimate of primary productivity per year for 1959-1960 is 38,958 mg $C \cdot m^{-2} \cdot year^{-1}$ and was considered the best estimate for comparison with recent years. This value indicates an increase of about 20% from 1959-1960 to 1968 and an increase of 51% from 1959-1960 to 1971 (Table 23). The graph of the annual primary productivity at Lake Tahoe between 1959 and 1971 is shown in Fig. 22. The curve that seems to fit the 1968 to 1971 data best was drawn through the four points and dotted back to the 1959-1960 value. The regression line (A) through the five data points and the regression line (B) through the four points of the recent years are also indicated.

We have examined a variety of relevant dependent variables including weather, light, and water chemistry and find that this is not explainable by the data we have on them. No change in these variables can account for this increase in primary productivity. Our observed change in annual incoming solar radiation, if it represents a real change rather than instrument fatigue (see Section IV), should have had the opposite effect on productivity of the lake and we should have seen a slight decrease. A rough comparison of nitrogen and phosphorus values can be made from the data collected in 1962 with that of the present (Table 24). Although the sampling sites were different between 1962 and the other year, and the analytical techniques used were not the same, the results would certainly seem to suggest a higher nitrogen concentration in the surface water of the lake in 1968, but these values dropped back the following years to the range measured in 1962.

It appears likely that the overall fertility of the lake has gradually continued to increase since 1959-60 (when less intensive data was collected) and that production has taken rather long to peak out after

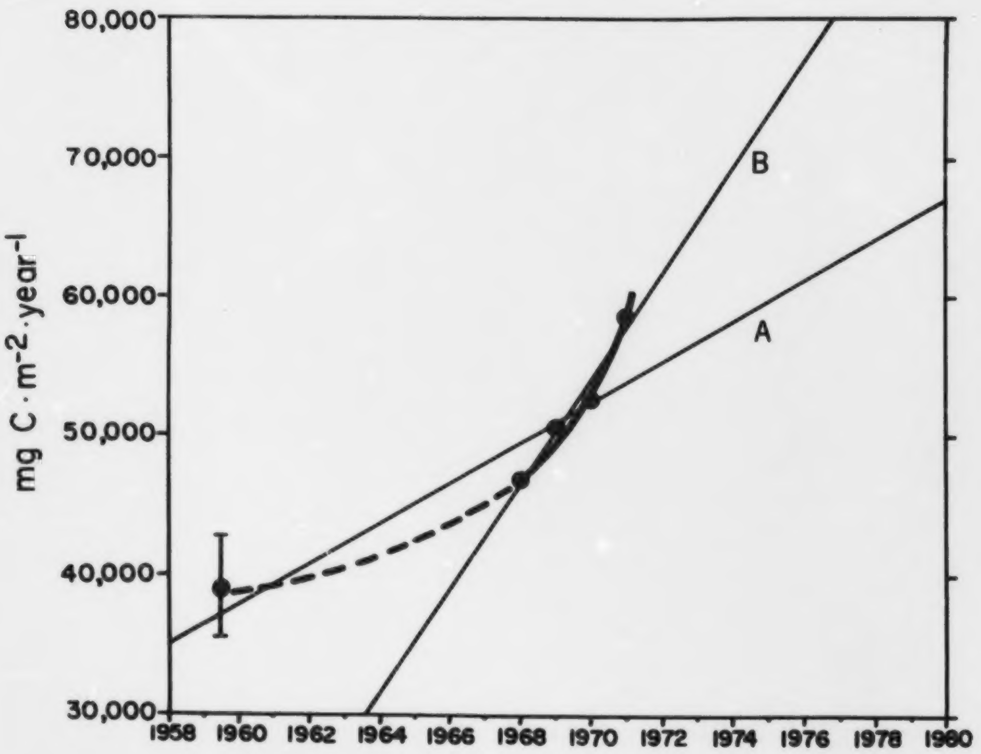

Figure 22. Annual primary productivity at Lake Tahoe between 1959 and 1971. The regression line (A) through 1959-60 and 1967-71 and the regression line (B) through 1967-71 are also indicated.

Table 24. A comparison of the nitrogen and phosphorus content (μg/l) of surface water of Lake Tahoe in 1962 and 1968-1971.

	NO_3-N	NH_3-N	P(total)
1962			
Number of samples	4	4	4
Range	2.0-6.7	--	--
Mean	5	2	7.5
1968			
Number of samples	10	13	11
Range	8.0-20.0	10.0-43.0	0.9-1.9
Mean	13.3	20.8	1.6
1969			
Number of samples	3		3
Range	0.0-5.0		2.6-3.9
Mean	2.0		3.0
1970			
Number of samples	9		10
Range	1.7-11.8		1.2-7.0
Mean	5.5		4.7
1971			
Number of samples	2		2
Range	4.1-5.3		3.3-6.3
Mean	4.7		4.8

sewage diversion began. This probably reflects continued loss from existing septic tank leach fields, continued loss from a land disposal site at South Shore (see Section VII), the fact that erosion and leaching have been increasing with the building boom, and finally, that the lake, as often noted, is extremely efficient in recycling nutrients once they enter the system.

Goldman and Armstrong (1969) comparing the average daily value for the one year of data from June 1959 through May 1960 to that of the one year of data from August 1967 through July 1968 speculated on whether or not the higher 1967-68 data reflected the high spring runoff of 1967 or actually evidenced an alarming increase in fertility over the previous eight years. We can now say with more assurance that, in view of the three and one half years of data following their measurements, the primary productivity for 1967-68 most probably reflected both. The alarming increase in fertility that was observed over the previous eight years was indeed a continuing trend in increasing fertility. The summer-fall data of 1967 was, however, unusually high (as can be seen from Fig. 18) and was probably influenced by the high spring runoff that year.

Careful scrutiny of primary productivity in Lake Tahoe is continuing and it will be of great interest to see how long this trend will continue. With the large block of data now available a model can soon be built which should enable us to predict with considerable confidence alternative futures at different levels of development for the productivity and transparency of this unusual lake.

The mean primary productivity per day for each month of each year was calculated from the monthly total which was obtained by integration. Results are shown in Figure 21. The curve of mean monthly productivity exhibits a steady shift in the seasonal maximum from one year to the next. The maximum, or peak of primary productivity, was recorded in

March 1968, in April 1969, then shifted further to May 1970, and finally to August in 1971. This corresponds in 1968 and 1969 to maximum seasonal primary productivity occurring while the lake was not stratified in the upper 120 m and while the profile of the primary productivity curve was unimodal with a maximum at a depth of about 50 m. In May 1970, the seasonal maximum corresponded to the onset of stratification and the onset of the two peaks in the profile. In 1971 the seasonal maximum in August occurred when the lake was strongly stratified and while the profile of the primary productivity curve was bimodal with two very accentuated peaks at about 10 m and 50 m (Fig. 19).

Several factors have been considered that might have caused the shift in seasonal maximum. The total amount of solar radiation per month for the months preceding the maximum in 1968 was not greater in 1968 than in the following years nor was the amount of solar radiation in March 1968 greater than in March of the following years (Fig. 4). Similarly, for the following years, the months of maximum primary productivity did not coincide with a month of unusually clear weather for that time of year nor did it coincide with unusually clear weather on the days when primary productivity was measured.

The curves of solar radiation (Fig. 3) show, however, that there were fewer very dark days in the first three months of 1968 than the following years (see Section IV), thus allowing the biomass of the phytoplankton to keep increasing early in the year (Fig.23). It is interesting to speculate on the causes of the subsequent shifts the following years. We know now that in some years (March 1973, Paerl et al. 1974) Lake Tahoe does mix all the way to the bottom (over 400 m). Some years, however, the lake mixes only partially. Good profiles of temperature below 135 m were not available until late in 1969 (see Section IV). How early and how well Tahoe mixes may determine the time and the size of the seasonal maximum of primary productivity through return of nutrients

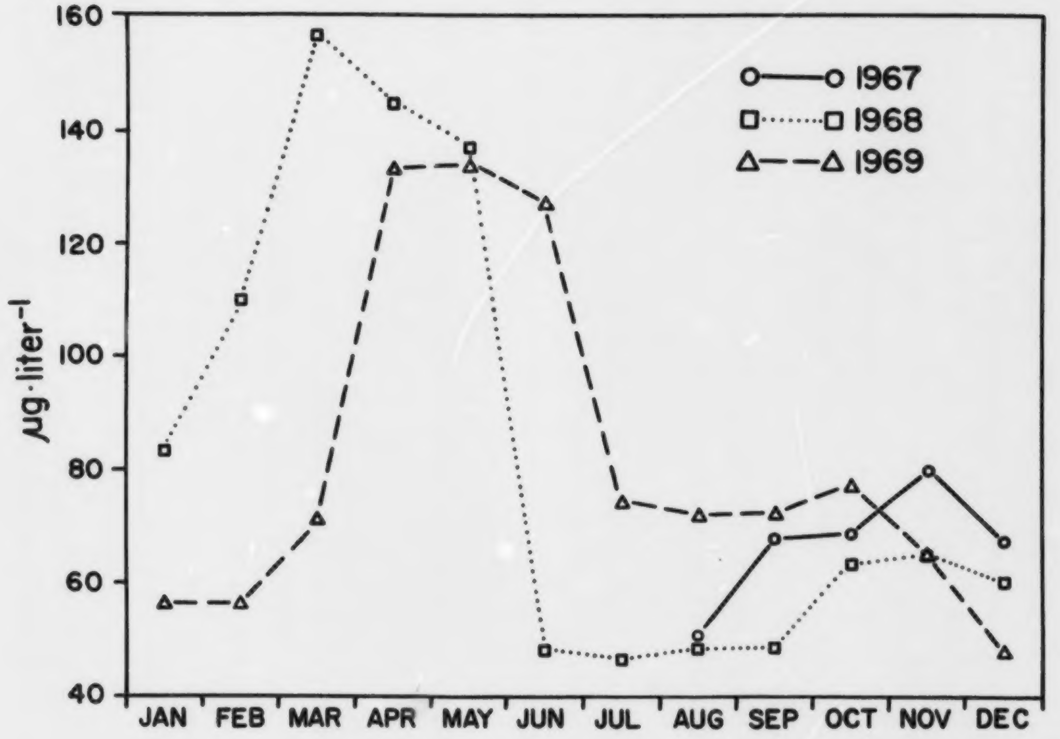

Figure 23. Seasonal phytoplankton biomass (mean for the euphotic zone) at the index station of Lake Tahoe from mid-1967 through 1969. Each point is the average for the month.

(particularly nitrate) to the euphotic zone. The year 1968 might have been a year when good growth conditions came early for the phytoplankton which then depleted the nutrients from the euphotic zone early in the season. Additional nutrients may not have been available from deeper depths to sustain the population if there was not a complete overturn in the late winter of that year. The unusually high population of zooplankton in May, June and July of 1968 could also have grazed down the phytoplankton population (see Section X). The year 1969 may have been similar to 1968 but had many more dark days (31 versus 14) during the first months of the year, which delayed the buildup of phytoplankton and the maximum of primary productivity (see Section IV). This maximum was, however, considerably greater than that of 1968. On the other hand, 1970, which saw the maximum of primary productivity occur in May at the onset of stratification, might well have been a year when there was moderately deep mixing in late winter. That year exhibits an initial small peak of primary productivity in February when the "profile" of productivity is unimodal and the water is not stratified in the upper 120 m. This was the time of year when the seasonal maximum of 1968 and 1969 occurred. The primary productivity dropped in March and April. A second and higher maximum occurred in May suggesting new nutrients were supplied in April to the euphotic zone.

The primary productivity curve for 1971 suggests good early conditions, which created a small initial seasonal peak in February and March, and perhaps complete or nearly complete mixing in the spring. Some evidence for mixing is found in the nearly homothermous conditions extending to 400 m (see Section IV, Table 6). Mixing may have resupplied enough nutrients to the euphotic zone to support a large second seasonal peak of primary productivity during stratified summer conditions when the depth profile of primary productivity is bimodal.

The shift in the seasonal peak of primary productivity was reflected in the phytoplankton biomass for the years 1968 and 1969 (Fig. 23). During these years all phytoplankton samples collected in parallel with primary productivity depths were enumerated. In 1968 the mean monthly biomass of the phytoplankton peaked in March. Its value was still high in April and May and dropped drastically in June of that year. In 1969 the phytoplankton biomass was highest in April, May and June with the peak value in May and a drastic drop in July.

The shift in the seasonal peak was also followed closely by the number of zooplankters. Their seasonal maximum occurred the month following the highest phytoplankton biomass values and one or two months after the maximum primary productivity.

In March 1968, at the time of the seasonal maximum of primary productivity, the phytoplankton biomass was dominated by the three diatom species which were also dominant the rest of the year. Fragilaria crotonensis had the highest biomass value followed by Cyclotella bodanica and Melosira crenulata (Fig. 24). From 6 March 1968 through 2 April 1968, 78% of the total phytoplankton biomass was accounted for by these three species. On 6 March 1968, when primary productivity was particularly high and had its maximum at a depth of 50 m, the bulk of the phytoplankton biomass was also found at 50 m. The three dominant species were the same diatoms as mentioned above, followed by the chrysophycean Dinobryon sertularia.

On 25 April 1969,at the time of maximum primary productivity, 89% of the biomass of the phytoplankton was accounted for by the three diatom species. These were dominant throughout the year in 1969, and consisted of Fragilaria crotonensis, Cyclotella bodanica and Melosira crenulata. The fourth most abundant diatom species that day was Stephanodiscus astrea. At 40 m depth where the local maximum occurred, the phytoplankton was dominated by these same species.

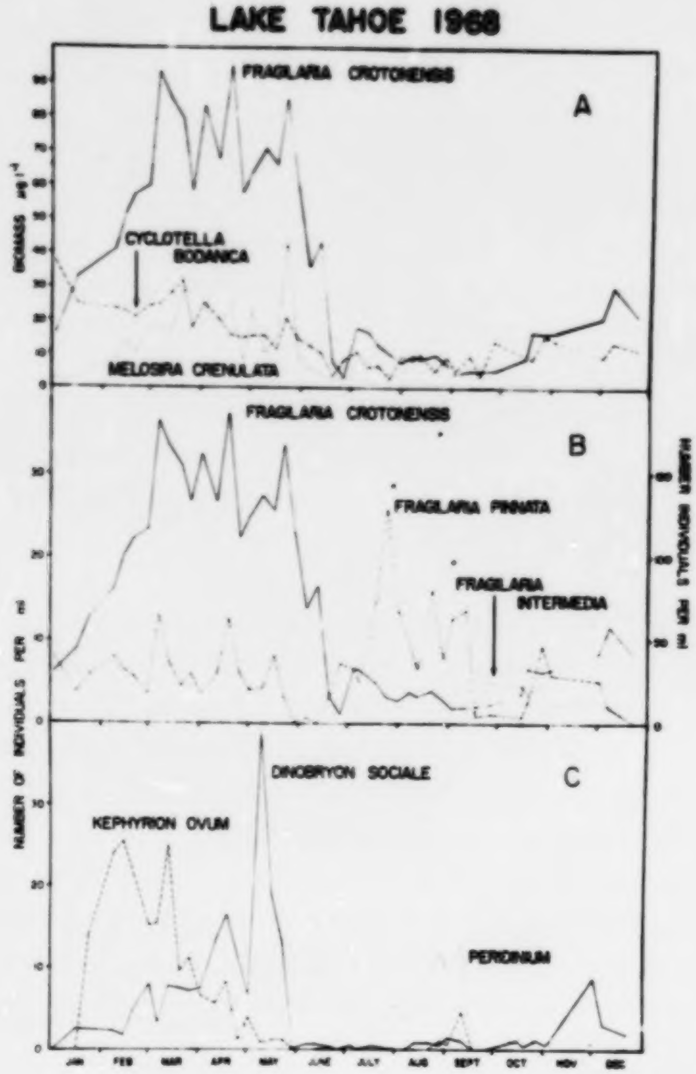

Figure 24. Seasonal variation of phytoplankton species at the index station of Lake Tahoe. Biomass variation of the three dominant species (A), variation in number of three species of Fragilaria (B), and variation in number of three flagellate species (C) found in Lake Tahoe in 1968.

In 1970, although we do not have all samples enumerated for that year, it appears that the dominant phytoplankton at the time of maximum productivity are *Synedra radians*, *Melosira crenulata* and *Cyclotella bodanica*. *Fragilaria crotonensis*, which frequently dominates, was only the fourth highest in biomass of the phytoplankton species.

We hope to be able to examine more closely in the near future the samples of phytoplankton for the years 1970 and 1971 to see if the change in time of occurrence of the maximum primary productivity created further changes in dominance of species of algae. Those species which are most efficient in utilizing available resources of nutrients, light, and temperature would be expected to become the dominant forms. There are major environmental variables at Tahoe which cause the wax and wane of the phytoplankton. The obvious influence of solar radiation, water temperature, and the amount of nutrient runoff from the watershed are further modified by the amount of wind mixing that occurs when stability is lowest. It may soon be possible to predict the algal growth in the lake by following critical winter and spring parameters.

PHYTOPLANKTON SPECIES COMPOSITION AND ABUNDANCE

Methods

From August 1967 through December 1971 a sample for phytoplankton enumeration was collected from the same Van Dorn sample each time primary productivity was measured. The water was collected in a 125 ml glass bottle and immediately fixed with neutral Lugol's solution. Preserved samples were then brought back to the central laboratory at Davis where preparation of slides, counting and data processing were done. The Millipore filter method was used throughout this study. In this method, 100 ml of the sample were filtered through AA Millipore gridded filters, 25 mm in diameter. The filters were then dried completely, trimmed and cleared with cedarwood oil. Filters were mounted on slides slightly to the left of the center, covered with coverslips and ringed with Hyrax. The counting was done using a stage restriction mechanism with the Wild M-40 inverted phase microscope. Black and white photographs of each species were taken with a polaroid camera attachment on the microscope. Photographs were collected in a book for future reference. A biomass estimate of an "average" individual of each species was done by approximating geometrically the volume of several individual cells, calculating the average volume of an individual of the species and converting it to fresh weight by assuming a density of one.

Raw counts were recorded directly on data sheets that have been specially designed for compatibility with the format required by computer data cards and by our computer program for phytoplankton data reduction. These special data sheets are such that no additional transcription or other work is necessary before having computer cards punched. At the same time these data sheets are sufficiently self-explanatory to be kept as a very good original record of phytoplankton raw counts. A computer program was developed that reduces all phytoplankton data and prints out results of phytoplankton concentration and biomass at each depth, total and average for the entire "integrated" column of water. This is printed for each species, for each class and for the entire phytoplankton population. Results of calculations of community diversity, diversity per individual, and redundancy are also printed at each depth where the phytoplankton has been sampled and for the entire column of water. The expression for diversity adopted for this program is the information measure of diversity used by Margalef (1958, 1965), Goldman et al. (1968) and Goldman (1970b).

Results and Discussion

There are over 160 species of phytoplankton in the waters of Lake Tahoe of which 129 are found at the index station. The phytoplankton population is composed mainly of diatoms of which there are 112 species. The rest of the phytoplankton consists of eight species of Chlorophyceae, three of Cyanophyceae, three of Chrysophyceae, two of Dinophyceae, and one Cryptophycea. Ten of the Bacillariophyceae are centric diatoms, the other diatoms are pennates. The name of each phytoplankton species identified at the index station together with its mean cell volume is given in Table 25.

All samples collected in parallel with the primary productivity at the index station between 9 August 1968 and 13 May 1970 were identified and enumerated. Samples from 22 additional dates in 1970 and 1971 were carefully examined for this report. Thirteen different depths were sampled for each date. Although some aspects of the results of 1970 and 1971 are considered, our main conclusions on the phytoplankton population in Lake Tahoe will be drawn from the results of 1967, 1968, and 1969 data.

The average number of cells per ml of the entire 105 m water column for each species on each sampling day is given in Appendix C. The values were obtained by examining 13 samples from 13 different depths between 0 and 105 m (except for early dates when the water column was sampled to 90 m only; see previous subsection). The number of cells at each depth were weighted according to depth and summed to obtain the overall integrated value of the total number of cells for each species present in the entire 105 m water column. This value divided by the number of ml of water in the water column is the average number of cells per ml. Some small flagellates were present in Tahoe, but because of difficulties in identification and enumeration are not reported here. Total

Table 25. Phytoplankton species found at the index station of Lake Tahoe, including cell volumes

Bacillariophyceae	Cell volume (μ³)
Cyclotella antiqua	635
Cyclotella bodanica	4778
Cyclotella ocellata	157
Cyclotella stelligera	77
Melosira crenulata	1209
Melosira granulata	1806
Melosira varians	4301
Melosira undulata	170950
Stephanodiscus astrea	707
Achnanthes clevei	350
Achnanthes exigua	300
Achnanthes flexella	880
Achnanthes lanceolata	420
Achnanthes linearis	120
Achnanthes nollii	265
Achnanthes peragalli	430
Amphiprora paludosa	96000
Amphipleura pellucida	4080
Amphora ovalis	2500
Asterionella formosa	480
Cocconeis disculus	500
Cocconeis placentula	503
Cocconeis rugosa	2513
Cymbella cuspidata	10000
Cymbella gracilis	4275
Cymbella lanceolata	6000
Cymbella ventricosa	1800
Cymbella sinuata	375
Cymbella prostrata	15750
Cymatopleura solea	37370
Diatoma anceps	1000
Diatoma hiemale	1060
Diatoma vulgare	3600
Diploneis elliptica	1781
Diploneis oculata	330
Diploneis finnica	11400
Eunotia naegelii	510
Eunotia tenella	590
Eunotia triodon	2500
Eunotia perpusilla	144
Eunotia pectinalis ventricosa	750
Eunotia pectinalis	1750
Epithemia sorex	5125
Epithemia turgida	66000
Epithemia zebra	11520
Epithemia argus	
Fragilaria crotonensis	520
Fragilaria intermedia	2500
Fragilaria pinnata	175
Fragilaria vaucheriae	235
Fragilaria construens	
Fragilaria leptostauron	[illegible]

Bacillariophyceae (cont.)	Cell volume (μ³)
Fragilaria capucina	140
Frustulia rhomboides	7600
Gomphonema acuminatum	610
Gomphonema parvulum	350
Gomphonema capitatum	6831
Gomphonema ventricosum	678
Hantzschia amphioxys	3580
Gyrosigma attenuatum	7800
Hannea arcus	1470
Mastogloia smithii	5184
Meridion circulare	1046
Navicula aurora	14016
Navicula bacillum	2000
Navicula cocconeiformis	980
Navicula exigua	1200
Navicula festiva	100
Navicula mutica	800
Navicula pseudoscutiformis	452
Navicula pupula	1000
Navicula radiosa	1100
Navicula scutelloides	980
Navicula capitata	105
Navicula cuspidata	12500
Navicula costulata	270
Neidium hitchcockii	14800
Neidium affine	9667
Nitzschia filliformis	1100
Nitzschia amphibia	200
Nitzschia sinuata	960
Nitzschia palea	
Opephora martyi	400
Opephora americana	560
Pinnularia biceps	4950
Pinnularia aestuarii	6360
Pinnularia subcapitata	2520
Pinnularia abaujensis	10103
Pinnularia rupestris	18000
Rhoicosphenia curvata	2900
Rhopalodia gibba	8000
Stauroneis phoenicenteron	6720
Stauroneis smithii	450
Stauroneis anceps	4394
Surirella ovata	13000
Synedra amphicephala	152
Synedra mazamensis	214
Synedra radians	1493
Synedra rumpens	420
Synedra socia	471
Synedra ulna	13200
Synedra [illegible]	190
Tabellaria fenestrata	2160
Tabellaria flocculosa	2770

Bacillariophyceae (cont.)	Cell volume (μ³)
Tetracyclus emarginatus	4400
Tetracyclus lacustris	3800
Diatomella balfouriana	660
Actinocyclus ehrenbergii	1968
Caloneis fenzlii	4875
Caloneis speciosa	2850
Biddulphia aurita	6000
Gomphoneis herculeana	6831
Chlorophyceae	
Elakatothrix gelatinosa	187
Scenedesmus quadricauda	134
Sphaerocystis schroeteri	268
Staurastrum paradoxum	2050
Botryococcus braunii	1469
Oocystis naegelii	
Pediastrum kawraiskyi	
Ulothrix aequalis	1000
Cyanophyceae	
Anabaena sp.	17000
Merismopedia elegans	2000
Polycystis aeruginosa	7939
Chrysophyceae	
Dinobryon sertularia	900
Kephyrion ovum	266
Mallomonas	
Dinophyceae	
Peridinium sp.	1400
Ceratium hirundinella	37000
Cryptophyceae	
Cryptomonas reflexa	3400
Euglenophyceae	
Flagellates	

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phytoplankton biomass at each depth on each sampling date is given in Appendix D.

The ten most dominant species in number of cells and the ten most dominant species in number of occurrences on a day were determined for each year of the study, for all years from 1967 through 1971 and for the three years from 1967 through 1969. This was done by comparing the total per year of the number of cells per ml of each species and ranking the species in order of decreasing number from the species with the largest number of cells enumerated that year to the species with the smallest number. Thirteen of the most dominant species on this basis have been graphed on a logarithmic scale using the computer, and are shown in Figure 25. The ten most dominant species for the years 1967-1969 were:

Fragilaria crotonensis
Melosira crenulata
Fragilaria pinnata
Stephanodiscus astrea
Cyclotella bodanica
Sphaerocystis schroeteri
Peridinium sp.
Dinobryon sertularia
Cyclotella ocellata
Kephyrion ovum

Three additional species were found to be among the ten dominant species when numbers were summed over the five years, 1967 through 1971. These were Synedra radians, Asterionella formosa, Navicula radiosa. Cyclotella stelligera, an uncommon species in Lake Tahoe for the years 1967-1971, is also presented in the graph. This species has been found in large numbers in some recent midlake samples (1972-1973 unpublished data).

The dominant species listed above were also among those species that occur the most frequently at the index station. Comparison of the

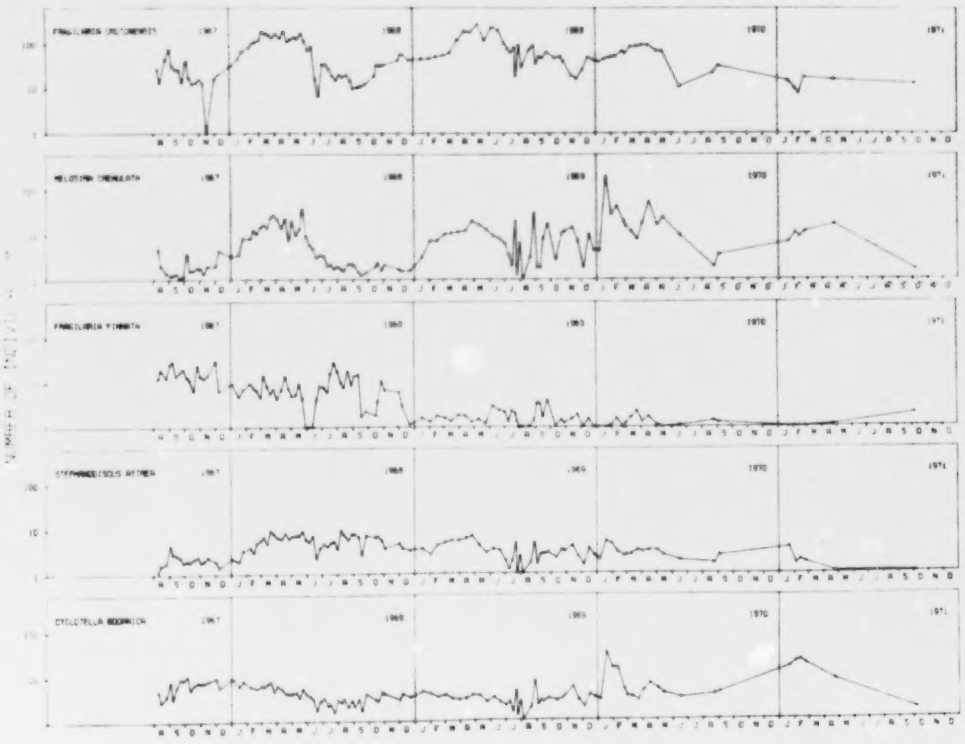


Figure 25a. Seasonal variation in numbers of the 13 most dominant phytoplankton species at the index station of Lake Tahoe from mid-1967 through 1971. Cyclotella stelligera and the total phytoplankton number are also shown.

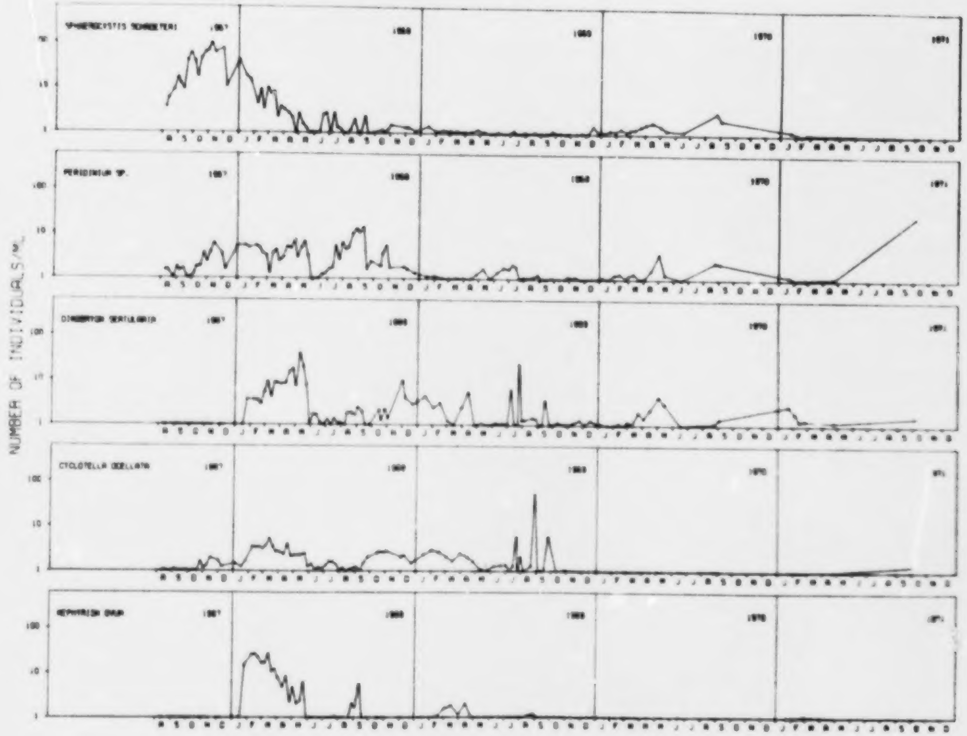


Figure 25b. Seasonal variation in numbers of the 13 most dominant phytoplankton species at the index station of Lake Tahoe from mid-1967 through 1971. Cyclotella stelligera and the total phytoplankton number are also shown.

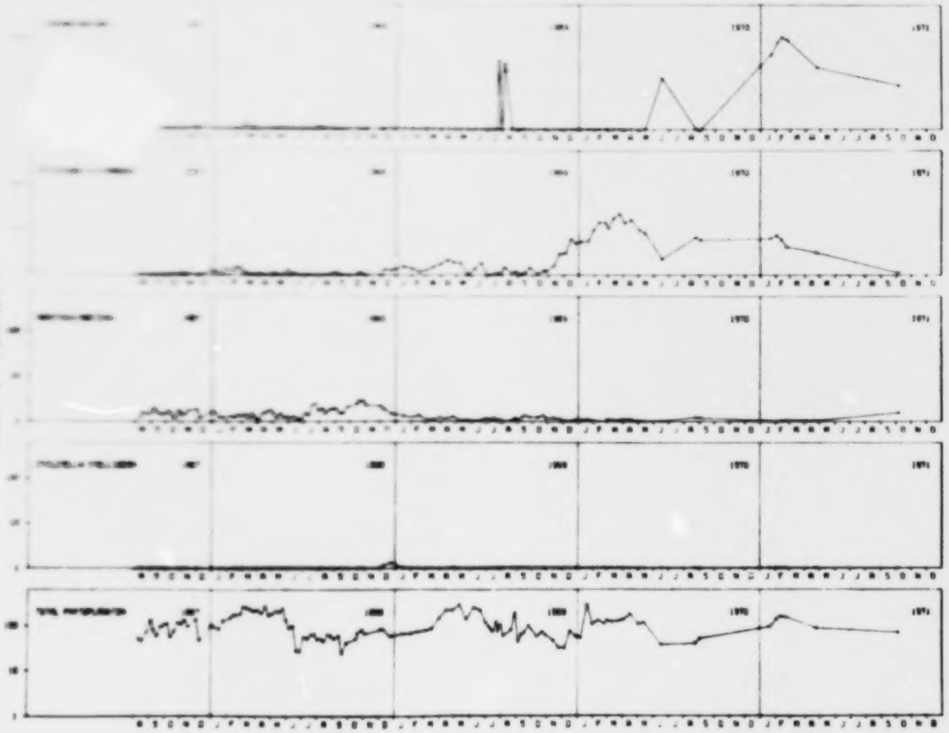


Figure 25c. Seasonal variation in numbers of the 13 most dominant phytoplankton species at the index station of Lake Tahoe from mid-1967 through 1971. Cyclotella stelligera and the total phytoplankton number are also shown.

seasonal variation in total phytoplankton population and the seasonal variation in Fragilaria crotonensis (Fig. 25) shows the importance of this species in the Lake Tahoe phytoplankton concentration. Three species dominated the biomass of the phytoplankton. The pennate diatom Fragilaria crotonensis formed by far the most important algal biomass and easily outgrew the two centric diatoms Melosira crenulata and Cyclotella bodanica (Fig. 24). These three species accounted for about 80% of the total biomass of the phytoplankton during most of the years 1968 and 1969. They were the dominant species during maxima of primary productivity (see previous subsection) and showed similar seasonal variation. Optimum growth for other species, however, was achieved at various other times of the year (Fig. 24). Some very clear successional patterns can be observed. In 1968 F. crotonensis peaked during the first half of the year, followed by maxima of two other species of the same genus after June (Fig. 24). Among the three important flagellates, Kephyrion ovum was replaced in May 1968 by Dinobryon sociale, which was in turn succeeded by Peridinium sp. (Fig. 24).

The mean monthly total phytoplankton biomass was evaluated by mathematical integration (as per mean monthly primary productivity; see previous subsection) for the data from August 1967 through December 1969 (Fig. 23). The biomass peaked in March-April-May 1968 following the seasonal primary productivity maximum of April 1969. This lag between maximum primary productivity and biomass of the phytoplankton is to be expected if the ^{14}C method is actually a measure of the rate of change of the biomass, i.e. the primary productivity is mathematically related to the phytoplankton as the first derivative of the biomass (Amezaga, Goldman, and Stull 1973). The phytoplankton data for Lake Tahoe in 1968 and 1969 seems to nicely support this well-established assumption.

The phytoplankton population, as indicated by mean monthly biomass, crashed in June of 1968 and in July of 1969. These months corresponded to the seasonal maximum of numbers of zooplankton which were probably grazing heavily on the phytoplankton and caused their decline. The importance of the loss of Daphnia rosea from the system is discussed in Section X and may well be related to the population shifts in phytoplankton observed.

SECTION VII

SYNOPTIC SURVEYS, BIOASSAYS, REMOTE SENSING, LAND DISPOSAL, AND NTA EXPERIMENTS

SYNOPTIC SURVEYS

Introduction

Culture experiments show that Lake Tahoe is deficient in available iron, that the interaction between nitrogen and phosphorus is complicated, and that the various tributaries of the lake differ greatly in their stimulation of algal growth (see following subsection; Goldman and Armstrong 1969; Goldman, Tunzi, and Armstrong 1969).

The areal variation in productivity in the lake was first documented during two synoptic studies in 1962 (Goldman and Carter 1965). Three small synoptic surveys were done in 1967. Thirteen synoptic studies covering a large number of stations were done between 1968 and 1971 and are reported here.

The present study is directed toward identifying the major sources of nutrients reaching Tahoe and the patterns of eutrophication they produce in the lake. The synoptic studies proved to be a particularly useful approach to the problem of identifying nutrient sources and evaluating their effect on adjacent Tahoe waters. These investigations include primary productivity of phytoplankton and some examination of species composition, biomass, and biotic diversity.

In addition, variation in periphyton growth and community over the whole lake is reported in Section IX and variation in benthic invertebrate organisms and their diversity is covered in Section XI.

Synoptic studies have often been made at sea where oceanographic vessels collect large numbers of samples in transects or over broad areas. Such collections are limited in their coverage by the time required for sampling each station and the slow speed of the vessels between stations. Further, most of the marine synoptics cover days, weeks, or months so that time and weather are important variables. Some improvement is anticipated as automated sampling and aerial reconnaissance techniques are improved, but the limitations indicated above still remain as serious problems. Synoptics covering physical and chemical parameters have been made in the Great Lakes (Ayers et al. 1958; Anderson and Rodgers 1963; Saunders, Trama, and Bachmann 1962). Synoptic surveys of two New Zealand lakes for water chemistry, phytoplankton, and zooplankton distribution were made by Fish and Chapman (1969). For primary productivity measurements, shipboard incubation has long been used for synoptic surveys at sea, and Sorokin (1959) used the technique in Rybinskii reservoir in Russia over a period of seven days in June. He found photosynthesis varied in different parts of the lake as much as tenfold during this period.

Because of the photosynthetic variation from day to day, reflecting changes in the composition of phytoplankton, nutrients, or weather, a synoptic covering the shortest possible time period will have the greatest precision for detecting variation in fertility within the system. The synoptic approach we developed for Tahoe is probably unique in covering the entire surface layers of a large lake in a single day without disrupting the natural light cycle of the organisms. The procedure includes a simultaneous in situ incubation of all the primary productivity samples at a single location. This eliminates the uncertainties associated with studies covering longer time periods with various light conditions or the necessity of using the unnatural light of deckboard incubation. It provides a nearly instantaneous measure of phytoplankton productivity, composition, and biomass over the whole lake.

Methods

The synoptic approach has evolved from the first series of synoptics done in 1962 to the 1968-71 series reported here. In 1962 eight stations were incubated in situ with varying incubation time from station to station. These were corrected to a daily value on the basis of a diurnal series of samples run simultaneously at an index station. In 1967 five different stations on three different dates were sampled for comparison of primary productivity. Incubations were done in a rotating incubator under constant artificial light at surface water temperature. Samples for each station were taken at two depths where the photometer measurements indicated 75% and 50% transmission of the available surface light. The following paragraphs describe the methods used in 1968 and subsequent years.

In the summer of 1968 three synoptic studies were conducted on 17 July, 12 August, and 2 September. Four were done in 1969 on 28 June, 31 July, 28 August, and 24 October. In 1970 synoptic sampling was extended to winter and spring sampling. The five synoptics that year were done on 28 February, 2 April, 1 July, 24 July, and 2 October. Only one synoptic study was done in 1971 on 14 July.

Thirty stations were selected for the initial design of large synoptic surveys of 1968. Twenty-five of these stations were located along the shore around the lake and five stations in the middle of the lake. In areas where it was desired to test for steep gradients in production, three stations were located relatively close together, such as for General Creek, Upper Truckee River, Cave Rock, and Incline Creek where one station was chosen near the mouth of the creek and one on each side. Some of these stations were eliminated in subsequent years at locations where it was found that more than one station was not necessary. Other stations were added in areas where the productivity gradient was found to be greater than expected.

Two boats were used to collect all the water samples within about a six hour time period. All the water samples were collected at night, between approximately 8:30 p.m. and 2:30 a.m., and stored in insulated boxes, so that no photosynthesis or sample warming was taking place and in order not to expose the organisms to surface light or otherwise disrupt their normal diurnal rhythm. Four depths were sampled in 1968: 0, 5, 10, and 15 m. The 5-m depth sample was eliminated the following years and replaced by a sample at 20 m. Water samples were collected in 125 ml Pyrex^R bottles for measurements of primary productivity using the ^{14}C method as modified by Goldman (1963) (see Section VI). A single light bottle and a dark bottle were used in 1968. Duplicate samples for light bottles were taken the following years. Strengthening and improvement of the field gear became necessary as the number of samples collected on a synoptic almost doubled. Phytoplankton and water chemistry samples were collected at the same time. All samples were returned to the index station located near Homewood on the west shore. This is near out laboratory where regular in situ productivity measurements are taken on a year round basis.

All primary productivity samples were rapidly injected with ^{14}C solution just before sunrise, lowered into the lake, and suspended at the same depths from whence they were collected. The bottles were left to incubate all day and were returned to the laboratory for filtration at sundown. Handling of the large number of samples collected during the synoptic was therefore accomplished only before any photosynthesis had occurred in the morning and after photosynthesis had ceased in the evening. This provided an equal incubation period for all samples so that the primary productivity measurements for all stations were comparable.

A "standard" index station (see Section VI) was sampled on the day of the synoptic incubation in order to make it possible to estimate synoptic primary productivity below 20 m for the entire lake.

Phytoplankton samples were collected for each station by pooling aliquots from each depth into one sample. The samples were fixed with neutral Lugol's solution and returned to Davis for identification, counting, and measurement of individuals for determination of their biomass. An inverted Wild^R microscope was used for this work.

The water chemistry samples for alkalinity determination were taken for each station at the 5-m depth only, since no significant change with depth down to 15 m was detected in Lake Tahoe. Carbon available for photosynthesis in 1968 was calculated from the pH, alkalinity, and temperature nomograph of Saunders, Trama, and Bachmann (1962). The more rapid and sensitive method of infrared CO_2 analysis after combustion with acid was used the following years.

Results and Discussion

In 1967 the variation in primary productivity was particularly high in August and September. Results were not converted to mg $C \cdot m^{-2} \cdot day^{-1}$, because samples were incubated under constant light which was not very representative of the lake conditions. Crystal Bay and South Shore were the highest stations in August and early September, respectively

(Fig. 26). With the onset of winter storms and mixing, the variation in stations disappeared in late September.

The 1968 synoptics provided a great deal more data than 1967. For each synoptic at each station the primary productivity for the day, under a square meter surface for the 15 m column of water, was calculated in mg $C \cdot m^{-2} \cdot day^{-1}$. Contour maps of primary productivity were constructed from this data (Goldman, Moshiri, and Amezaga 1972). For the first synoptic, the range of values was from 11.04 mg $C \cdot m^{-2} \cdot day^{-1}$ in a midlake station to 78.52 mg $C \cdot m^{-2} \cdot day^{-1}$ at the mouth of Incline Creek. For the second synoptic, values ranged from 12.41 mg $C \cdot m^{-2} \cdot day^{-1}$ in a midlake station to 90.86 mg $C \cdot m^{-2} \cdot day^{-1}$ at Tahoe City. For the third synoptic, values ranged from 17.85 mg $C \cdot m^{-2} \cdot day^{-1}$ at a midlake station to 84.07 mg $C \cdot m^{-2} \cdot day^{-1}$ at the mouth of the Upper Truckee River.

Productivity values in mg $C \cdot m^{-2} \cdot day^{-1}$ were also calculated in 1969 for the 15-m water column at all stations except near Tahoe City where bottom depth is 10 m. Results from the first synoptic on 28 June had a range of 3.2 to 43.3 mg $C \cdot m^{-2} \cdot day^{-1}$. Highest values were measured in Crystal Bay and the Kings Beach-Brockway area on the north end and along the southeast shore from the Upper Truckee River inflow to Zephyr Cove. Isolated high production areas occurred at Glenbrook Bay, midlake south, and Emerald Bay. The average productivity per station was 20.02 mg $C \cdot m^{-2} \cdot day^{-1}$.

For the second synoptic, the range of values was 8.7 to 96.6 mg $C \cdot m^{-2} \cdot day^{-1}$ and the average per station was 40.91 mg $C \cdot m^{-2} \cdot day^{-1}$. The second synoptic of 1 August indicated an overall productivity of the upper 15 m of Lake Tahoe twice that of the first synoptic at the end of June. The northern and eastern shore stations again exhibited high productivity. High values were recorded for the first time at the midlake station and midlake south stations. As expected, high values

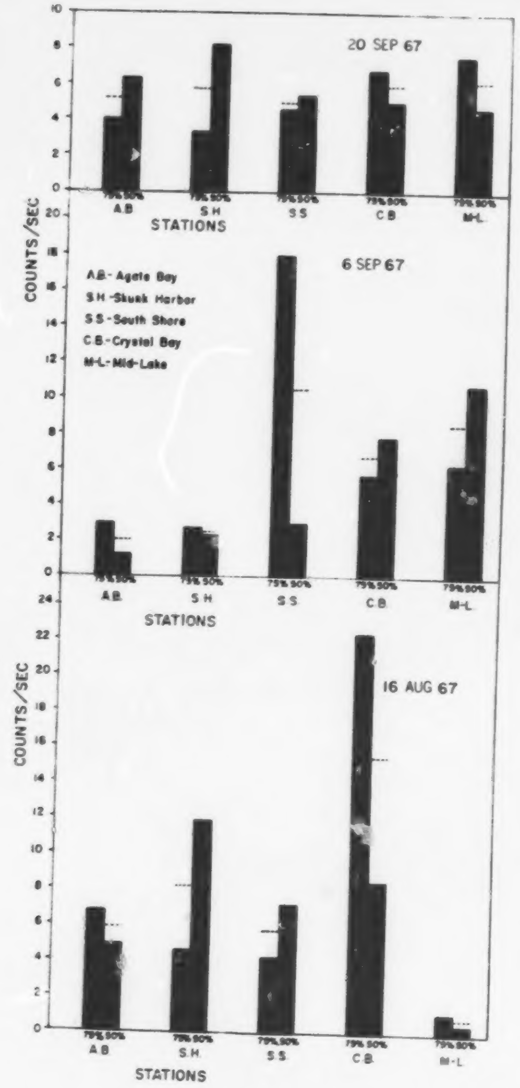


Figure 26. Primary productivity measurements at five stations in Lake Tahoe during three different sampling periods in 1967 at the two depths where 75% and 50% light were transmitted.

occurred at the south shore and Emerald Bay.

The third synoptic on 28 August indicated an increase in average productivity per station to 48.37 mg $C \cdot m^{-2} \cdot day^{-1}$, while the range of values from 10.9 to 89.2 mg $C \cdot m^{-2} \cdot day^{-1}$ did not differ appreciably from earlier measurements that year. On that day, the highest value was again recorded at Emerald Bay. The unique morphometric and limnological conditions of Emerald Bay isolates it somewhat from the main waters of the lake. Therefore, high measurements in Emerald Bay should not be considered too critical when assessing the changes in the primary productivity of the main Tahoe waters. The pattern of areal variation in productivity of the third synoptic was similar to that of the second. The 25 October synoptic values were lower with an average of 28.73 and a range of 18.4 to 38.0 mg $C \cdot m^{-2} \cdot day^{-1}$. The decrease in the range of station-to-station variation during this fall sampling indicates the decreased inflow from tributaries, which provides less potent localized sources of nutrients capable of influencing the primary productivity of the lake. There was no definite trend in the variation of productivity over the whole lake. Values above 30 mg $C \cdot m^{-2} \cdot day^{-1}$ occurred from Tahoe City on the northwestern shore to Sand Harbor on the northeastern shore. Similar values in the southern half of the lake were found along the southeastern shore and at one location on the southwestern shore.

During 1970 a total of five synoptics were run. They produced a large amount of data on both spatial and temporal changes in Lake Tahoe primary productivity by covering part of the winter and spring as well as the summer. The seasonal variation in the average productivity for the whole lake followed the same pattern as that of the productivity at the index station (see Section VI, Fig. 21). The average was 42.9 mg $C \cdot m^{-2} \cdot day^{-1}$ (for the 20-m water column) in February. It was lower in April, increased in July, was highest at the end of July (108.7 mg

$C\cdot m^{-2}\cdot day^{-1}$), and was still very high in early October (83.6 mg $C\cdot m^{-2}\cdot day^{-1}$). Emerald Bay had the highest primary productivity values of all stations on all synoptics, except on 2 April when productivity was found to be slightly higher at Camp Richardson. The other stations with unusually high primary productivity values were Dollar Point on 28 February, Bijou on 1 July, and off Incline Creek on 24 July and 2 October. The values were 62.5, 53.6, 86.4, 177.7, and 101.9 mg $C\cdot m^{-2}\cdot day^{-1}$ to a depth of 20 m, respectively.

A new station was sampled in Tahoe Keys (an enclosed marina) in 1970. Values of primary productivity at that station were found to be 3.4 to 19.2 times larger than that of the highest value in the lake. The lowest values of primary productivity were recorded at the midlake station off State Line on 28 February, at Tahoe City on 2 April, at Camp Richardson on 1 July and 24 July, and at Al Tahoe on 2 October. The values were 17.8, 15.6, 25.2, 65.1, and 63.4 mg $C\cdot m^{-2}\cdot day^{-1}$, respectively.

One synoptic survey covering the entire lake was conducted in 1971 on 14 July. The highest value of primary productivity for the stations in the lake's main waters was 128.41 mg $C\cdot m^{-2}\cdot day^{-1}$ measured off Incline Creek. The value at Emerald Bay was 193.1 mg $C\cdot m^{-2}\cdot day^{-1}$. At Tahoe Keys it was 127.34 mg $C\cdot m^{-2}\cdot day^{-1}$ for the 5 m of water sampled there or about four times as high as off Incline Creek. The lowest value on that day was measured at the center of the lake (61.1 mg $C\cdot m^{-2}\cdot day^{-1}$).

For each station, the average of all synoptics was calculated for each year. A contour map of primary productivity in the lake was drawn based on the average of all synoptics surveyed the same year (Fig. 27). Primary productivity values per square meter were standardized to a 15-m water column for all years.

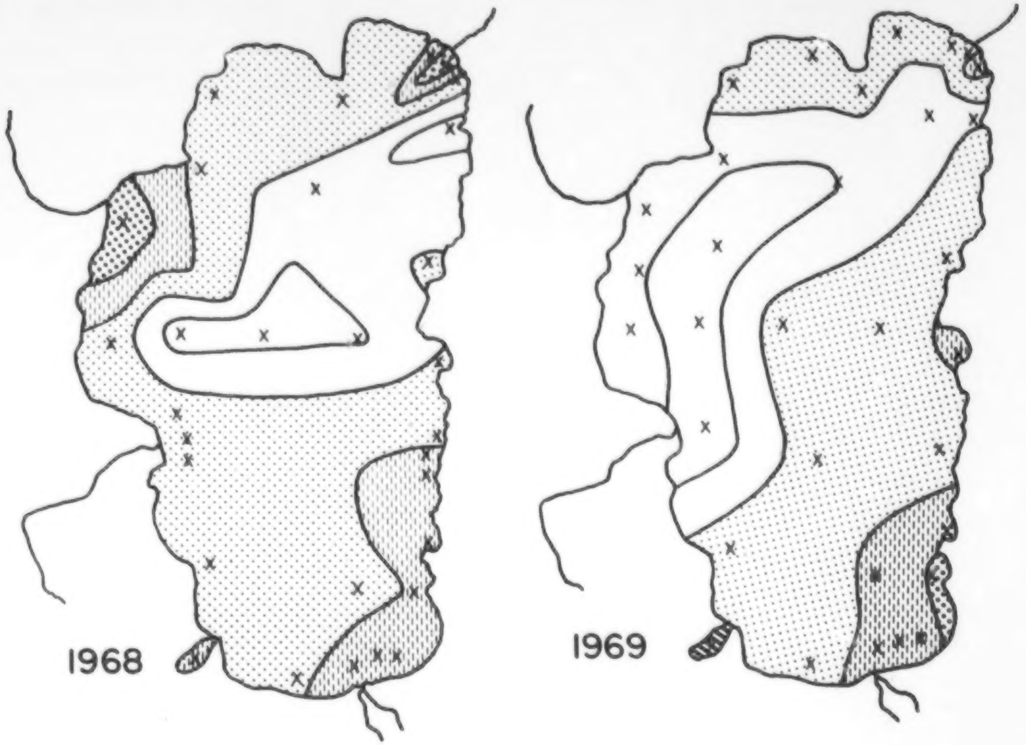


Figure 27a. Contour maps of primary productivity in the upper 15 m of Lake Tahoe in 1968-1971 based on the average of all synoptics surveyed the same year. Three synoptics were run in 1968, four in 1969, five in 1970, and one in 1971.

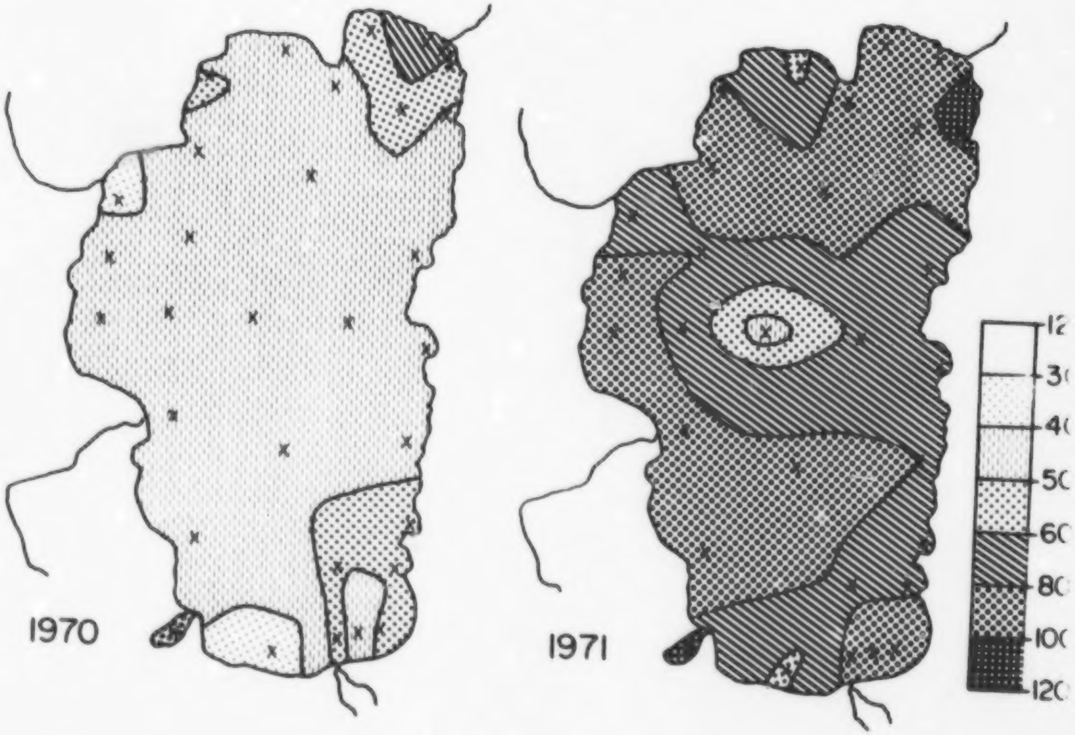

1970
1971
12
3
4
5
6
8
10
12

Figure 27b. Contour maps of primary productivity in the upper 15 m of Lake Tahoe i
based on the average of all synoptics surveyed the same year. Three sy
were run in 1968, four in 1969, five in 1970, and one in 1971.

The overall primary productivity of the lake increased from [illegible] to 1971 as did the primary productivity at the index station (see Section VI). Quantitative evaluation of the overall increase from one year to the next cannot be based, however, on the average synoptic values per year since they are not all representative of the whole year or the same time period (see Section VI).

Variations in areal distribution of primary productivity, however, are very well documented by these synoptic contour maps. The range of average values varied by fourfold in 1968 and 1969, from 14.9 mg $C \cdot m^{-2} \cdot day^{-1}$ at a midlake station to 58.8 mg $C \cdot m^{-2} \cdot day^{-1}$ at Tahoe City in 1968 and from 12.4 mg $C \cdot m^{-2} \cdot day^{-1}$ at the midlake station to 51.8 mg $C \cdot m^{-2} \cdot day^{-1}$ at Elk Point in 1969. The range of average values varied by twofold in 1970 and 1971, from 33.9 mg $C \cdot m^{-2} \cdot day^{-1}$ at Camp Richardson to 68.6 mg $C \cdot m^{-2} \cdot day^{-1}$ off Incline Creek in 1970 and from 45.7 mg $C \cdot m^{-2} \cdot day^{-1}$ at the center of the lake to 105.1 mg $C \cdot m^{-2} \cdot day^{-1}$ off Incline Creek in 1971. The spatial patterns of primary productivity appear not to be random, but ordered. Primary productivity is often high near shore and at the mouths of creeks. It is generally low at stations near the middle of the lake.

A comparison of pelagic and littoral zone phytoplankton primary productivity from 1968, 1969, 1970, and 1971 synoptic studies indicates a steady increase in the fertility of the pelagic zone relative to the littoral (Table 26). In 1968 the pelagic productivity per unit of surface area was only 51% of the littoral. It increased to 78% in 1969 and 96% in 1970. Only one synoptic was conducted in 1971 in which pelagic productivity was 90% of the littoral.

Two logical, but not unrelated explanations for this shift are proposed. First, that the fertilized littoral zone water mixes into at least the upper levels of Tahoe each winter, so that the pelagic euphotic zone

Table 26. Lake Tahoe synoptic surveys. A comparison of the mean primary productivity of the upper 15 m of water at the pelagic stations and the littoral stations (excluding Emerald Bay and Tahoe Keys).

	mg $C \cdot m^{-2} \cdot day^{-1}$		
	Pelagic	Littoral	$\frac{\text{Pelagic}}{\text{Littoral}}$
1968			
July 17	16.24	28.94	
August 12	20.30	43.24	
September 2	23.83	46.42	
Average	20.12	39.53	51%
1969			
June 28	14.40	20.96	
August 1	35.11	40.50	
August 28	36.32	50.78	
October 25	25.72	29.83	
Average	27.89	35.52	78%
1970			
February 28	28.97	30.55	
April 2	21.33	21.68	
July 1	38.12	41.76	
July 24	84.95	89.38	
October 2	61.84	62.86	
Average	47.04	49.25	96%
1971			
July 14	75.66	83.81	90%

increased in fertility each year relative to the consistently more fertile littoral zone, whose nutrients are replaced more directly by spring inflow. This inflow may be at least partially isolated from the pelagic zone during the summer months by a thermal bar. This hypothesis is supported by the steady increase in productivity at the index station each year of the study (see Section VI). The second explanation is that the littoral periphyton have taken up a larger and larger amount of the available nutrients each year leaving fewer for the littoral phytoplankton. A combination of these two explanations probably provides the most likely cause of the increase in pelagic productivity relative to that in the littoral zone.

Studies of the phytoplankton enumeration, biomass, and diversity for the synoptic surveys of 1968 have been reported by Goldman, Moshiri, and Amezaga (1972). These authors further investigated the significance of the difference between shallow water and deep water productivity, phytoplankton concentration, and diversity. The results of a student t test have been discussed by these authors.

The synoptic approach is very useful in studying cultural eutrophication as it enables the investigator to accurately locate sources of nutrients before the entire lake has undergone change. Lake Tahoe shows several areas of increased fertility. These are at the South Shore under the influence of the Upper Truckee River drainage and high resident population (Goldman et al. 1973, 1974), in Crystal Bay where Incline Creek and Third Creek drain highly disturbed land, and near the outflow of the lake (Tahoe City) where there is both a high resident population and fairly extensive areas of shallow water. One should note, however, the decrease from 1968 to 1971 in the high fertility observed off Tahoe City relative to other areas. It might be a direct consequence of the sewage treatment and effluent diversion from the north end of the lake, which is currently disposed of in a volcanic cinder cone. Further, much of the construction in the area was complete by 1971 and surface erosion from disturbed building sites may be on the decline.

Despite the lake's great volume for dilution of the annual inflow, local nutrient sources are altering the productivity pattern around the lake. A spring bloom of algae, which actually turned Tahoe's traditionally blue water green, has already been observed at the south shore and periphyton growth has become luxuriant around the entire margin during the last decade. In August 1969 following extensive land disturbance associated with construction of a golf course and a subdivision, Third Creek was found to be extremely stimulating to growth of Tahoe algae. In the experiment summarized in Figure 35 (discussed in following subsection), 10% of this stream water added to Tahoe's natural phytoplankton population stimulated photosynthesis by over 600%. When compared with controls, Incline Creek and the Upper Truckee River were also notable lake fertilizers in contrast to relatively undisturbed General Creek. This is not surprising since the Incline Creek drainage has been recently subdivided for homes and drains a fertilized golf course while the Upper Truckee River and some of its tributaries have also suffered considerable disturbance. Further, this drainage was used for some time as a land disposal site for treated sewage. The sewage is now being exported out of the basin, but the land disposal site still provides a drainage very high in nitrogen (see subsection on Land Disposal).

Tahoe is unquestionably changing. The synoptic approach provides a nearly instantaneous evaluation of conditions as they exist on a given day. Close monitoring of wind and currents could add further to our understanding of water transport in the lake as it affects the presence and movement of more fertile water masses. In general, the primary producers must be viewed as a more sensitive indication of increased fertility than chemical parameters, since any addition of nutrients to the lake appear to move rapidly into the phytoplankton. We characteristically find little or no measurable change in water chemistry (see Section V, Table 11), while phytoplankton photosynthesis is showing significant change. If the quality of our lakes is to be conserved, synoptic studies can be a great aid in locating and defining the influence of nutrient sources. When combined with bioassays (see following subsection), the relative stimulation capacity of various sources can be quantified and corrective measures taken before accelerated eutrophication destroys the quality of the entire lake.

BIOSTIMULATORY EFFECTS OF NUTRIENTS ON LAKE TAHOE PHYTOPLANKTON

Introduction

Bioassays utilizing the carbon-14 method were part of the Tahoe research program's evaluation of the contribution of chemical nutrients and nutrients contained in natural tributary waters to algal growth rate in the lake. Biostimulation by allochthonous sources and the implications of this to lake enrichment have been well documented for a number of lakes, including Lake Tahoe (Goldman 1964), and recently by Likens (1972). Considerable evidence has been gathered on the seasonal variation in biostimulatory effect caused by streams both under and away from the influence of "cultural eutrophication". Although the role and relative importance of nitrogen, phosphorus, iron, and micronutrients has been rather well clarified, additional work is continuing as part of the ongoing NSF-RANN project to extend our understanding of the complex interaction of nutrient limitation in Lake Tahoe.

The rapid human population increase in the Tahoe basin and the corresponding inhabitation and disturbance of several major watersheds appears to be a major factor in increasing the seasonal effect of tributary biostimulation of the lake. Sedimentation to the lake is increased over the natural levels by human activities (State of California Resources Agency 1969) and eutrophication is occurring in Tahoe at an accelerated rate (see Section VI). In addition, it should be noted that nutrient interactions and species-specific requirements may change the lake phytoplankton population if eutrophication is further accelerated. Studies indicate that nitrogen and, to a lesser extent, iron and phosphorus are now the most important nutrients which are in low supply and individually or in combination reduce or "limit" the growth of Tahoe phytoplankton. One member of our limnology group once commented that limiting factors might best be defined as "what does not happen in terms of what is not there" (Richard Armstrong personal communication).

Methods

Lake Bioassays For Nutrient Stimulation -

^{14}C bioassays were performed according to the procedures developed and modified by Goldman (1963). Water from an offshore station was collected for the bioassays in a clean, non-metallic, opaque Van Dorn sampler from the depth of maximum primary productivity (20-50 m) and held in an opaque carboy for sub-sampling. Acid-leached and distilled water-rinsed 500-ml Pyrex^{R} screw-cap Erlenmeyer flasks were filled after addition of ^{14}C to the carboy. To each flask was added the nutrient solution(s) to produce the final desired concentration. Samples were taken from the cultures for initial and final phytoplankton enumeration and identification as well as to determine nutrient concentrations. ^{14}C uptake measurements were made daily for a period of from 5 to 7 days by filtering 50 ml subsamples on HA Millipore^{R} filters and counting with an automatic, ultra-thin window, gas flow GM counter.

Lake-Tributary Bioassays -

Methods were similar to the above except that freshly collected, unfiltered stream water was added in 0.1, 1, and 10% concentrations to the lake water. Cultures were usually run in triplicate and under either a 12- or 24-hour light cycle in a rotating shelf incubator, with temperature set at the *in situ* lake level. Water samples were collected from the mouths of the Upper Truckee River, Third, Incline, and General Creeks, and the upper, middle, and lower portions of Taylor Creek.

Results

Nutrient Biostimulation of Lake Water -

Concentrations of nutrients in Lake Tahoe are generally very low at all depths (Fig. 28) and particularly in the euphotic zone at the depths of greatest biological utilization. Nitrogen compounds range from 2 to 20 $\mu g \cdot l^{-1}$ NO_3-N and NH_3-N is frequently undetectable. Total phosphorus is usually less than 5-10 $\mu g \cdot l^{-1}$ and iron is similar to nitrogen in concentration. A recurring problem with nutrient measurements at Tahoe is that the results are usually at or near the lower limit of detection by the most sensitive methods available (Strickland and Parsons 1968). A number of modifications of existing methods have been developed which are included in Appendix E.

Although nitrogen is probably the most limiting nutrient in Lake Tahoe, indications are that biostimulation of Tahoe phytoplankton by nitrogen and/or phosphorus is complex (Fig. 29). Acting in concert, moderate levels of addition of both nutrients will produce a greater stimulation than either one added singly (Goldman 1972). This is also true for additions combining nitrogen and iron (Fig. 30). Increasing growth of phytoplankton over control values is dependent upon the availability of NO_3-N and also on the presence of Fe. This is especially significant now that it has definitely been established that, at least during some

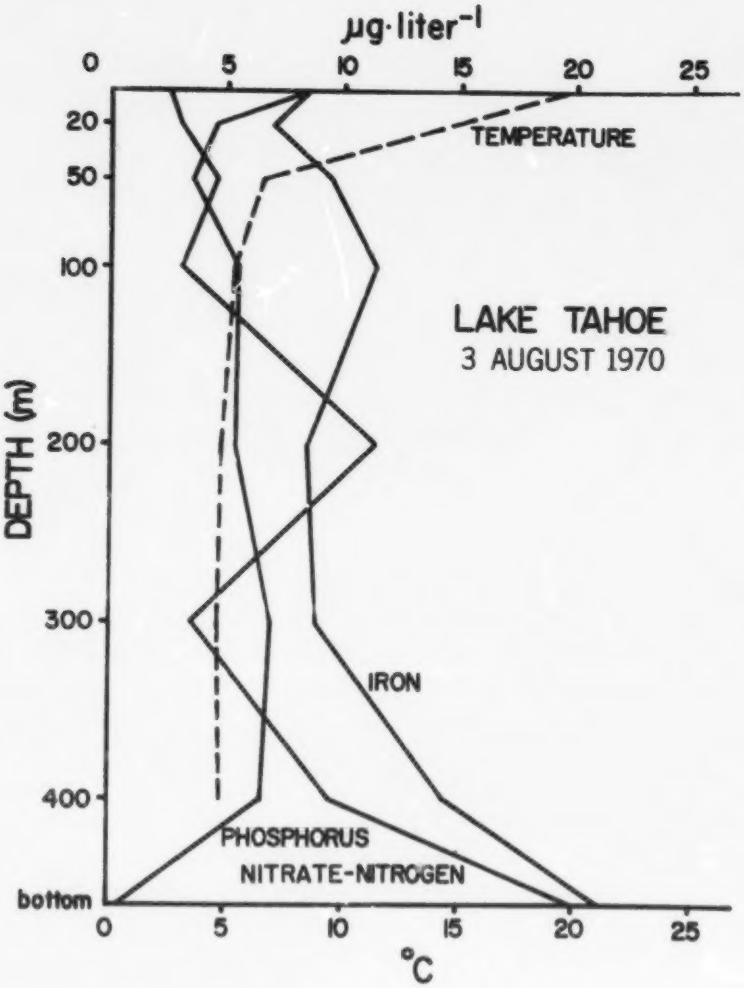


Figure 28. Deep water measurements of total iron, nitrate-nitrogen, total phosphorus, and temperature at the mid-lake station of Lake Tahoe on 3 August 1970.

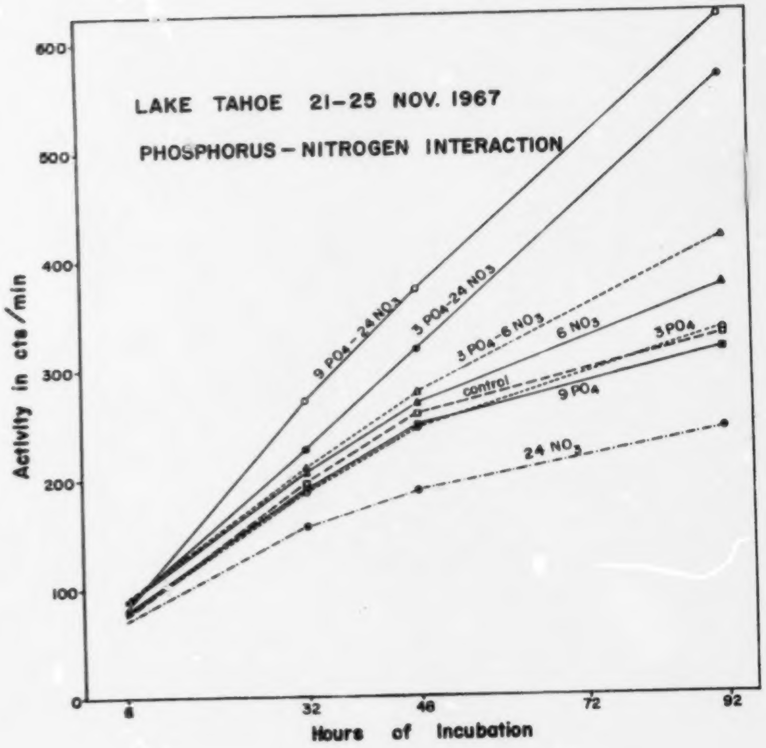


Figure 29. Bioassay of nitrogen and phosphorus additions (μg/1) to Lake Tahoe water.

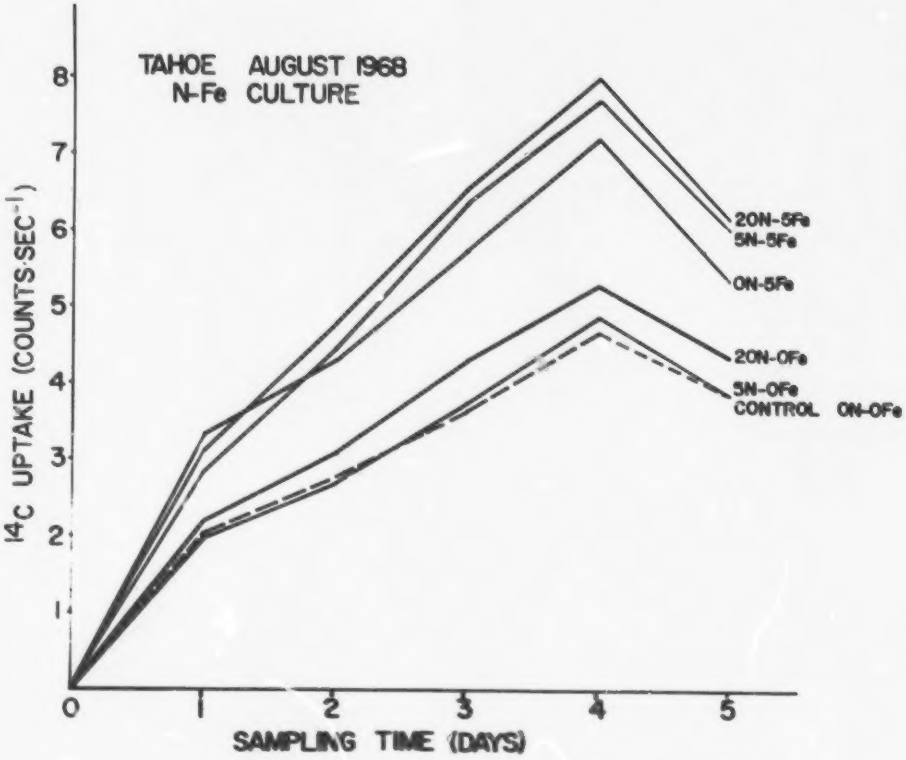


Figure 30. Bioassay of nitrogen and iron additions (μg/l) to Lake Tahoe water.

years, Tahoe mixes all the way to the bottom and returns relatively nutrient-rich water to the photosynthetic zone to fuel the spring phytoplankton blooms (Paerl et al. 1974).

Tributary Water Biostimulation of Lake Water - Several of the streams flowing into Lake Tahoe have been used as examples of watersheds under the influence of different levels of human activity. The amount of activity is in close agreement with the amount of biostimulation that each watershed contributed per unit volume to the lake.

Aside from some differences in natural geochemical input, erodibility of watersheds as well as climatic, elevational, and vegetational variations, it is increasingly obvious that certain Tahoe watersheds are more "polluting" (unnaturally biostimulatory) than others.

Although all streams contribute nutrients to the lake, General Creek is a good example of a reasonably unpolluted stream which when added to Tahoe does not exhibit a pronounced stimulatory effect (Fig. 31). Seasonal variation is very low from winter to summer in comparison to the Upper Truckee River (Fig. 32) even though the water chemistry levels can vary (see Section V). The General Creek watershed has a dense vegetative cover, usually carries low sediment loads even during snowmelt periods, and flow levels are not as variable as many other Tahoe streams. Despite some history of lumbering in its upper reaches, it appears to be enriching Lake Tahoe at a natural rate and may be considered a fairly typical Tahoe tributary stream.

The Upper Truckee River (Fig. 32) also exhibits a small stimulatory effect on the lake in the winter months, but produces very significant algal stimulation in the spring during peak snow melt runoff. This is noteworthy because the Upper Truckee River produces 30-40% of the total

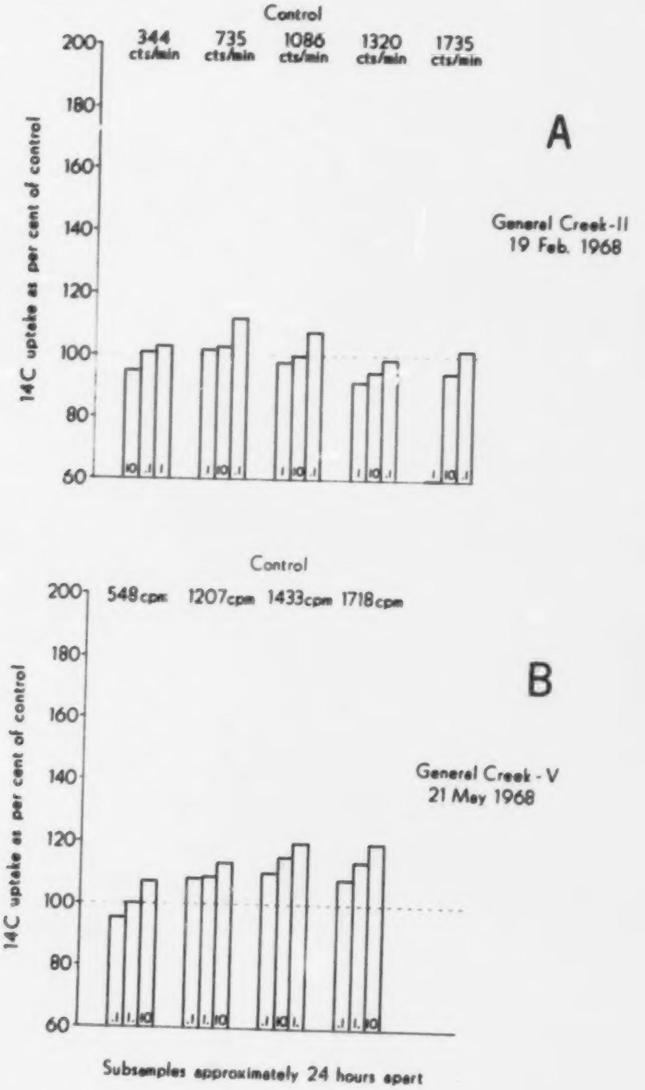


Figure 31. Bioassay of General Creek water additions to Lake Tahoe water. General Creek was selected as the best example of an unpolluted stream available. Low biostimulation was observed in both winter (A) and spring (B).

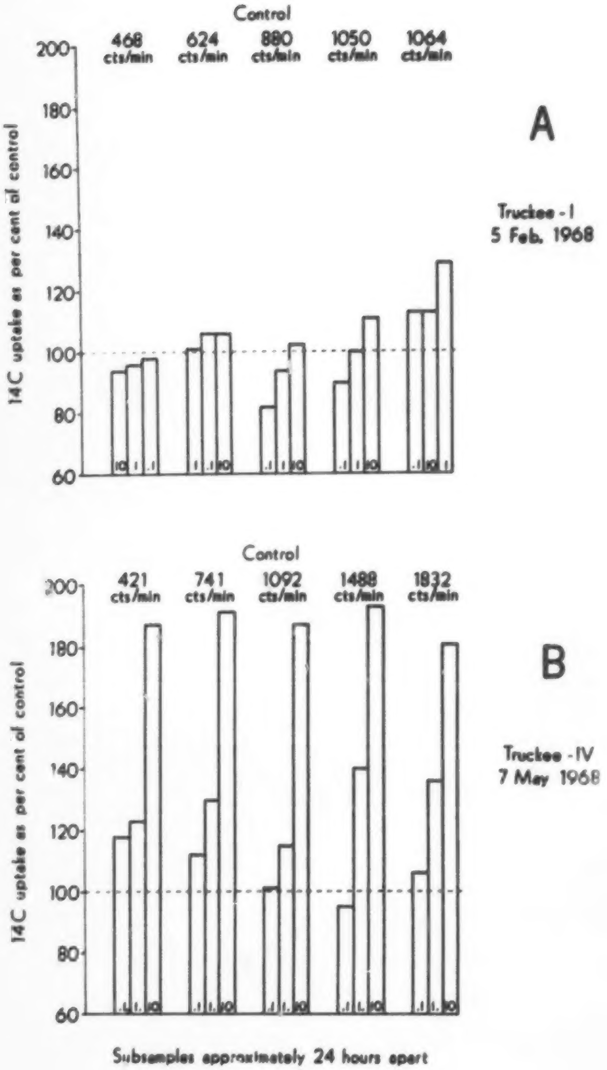


Figure 32. Bioassay of Upper Truckee River water additions to Lake Tahoe water. Stimulation was greatly increased from winter (A) to spring (B).

tributary inflow to Lake Tahoe and the stimulatory effect of this river is quite significant in terms of volume and area affected by the inflowing water mass (Goldman et al. 1974). A doubling of primary productivity is apparent when lake water is diluted by 10% with Upper Truckee water.

It should be noted that this condition is not limited to this large stream. Incline Creek (Fig. 33) exhibits a similar pattern in biostimulatory potency. It is very low or actually inhibits lake phytoplankton growth in the winter, but shows a large increase in biostimulation by the end of May when peak flows predominate. The "inhibitory" response exhibited may be simply dilution or lack of some essential nutrients or initial light shock which organisms may suffer when collected from below the surface of the lake.

Another tributary studied in more detail has been Taylor Creek (Fig. 34). This stream while under the moderating influence of an upstream lake (Fallen Leaf Lake) which regulates flow, clarity, and to some extent nutrient input, nevertheless shows significant winter-summer changes in biostimulation of the lake water phytoplankton and also produces some variation in response with the location of creek water collection for the bioassay. As with the other streams, Taylor Creek winter bioassays showed little or not positive response, especially from the lower station. This was probably due to the nutrient stripping actions of the stream periphyton community as the water passed toward the lake. However, in the late spring during peak snowmelt, the stimulation at all three stations was about 240% above the lake water controls, indicating that even streams with moderating influences such as lakes and relatively undisturbed watersheds can have a biostimulatory effect upon the lake. It should be remembered that although the Taylor Creek watershed is not undergoing rapid development, a significant human population does exist upstream along Fallen Leaf Lake's shore and on a

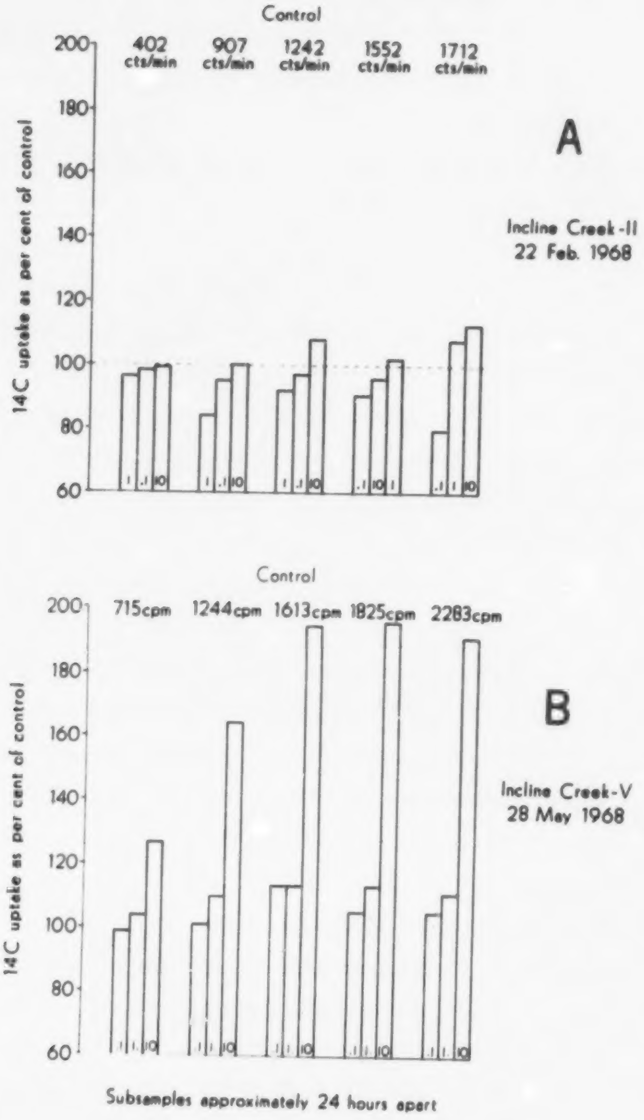


Figure 33. Bioassay of Incline Creek water additions to Lake Tahoe water, Stimulation was greatly increased from winter (A) to spring (B).

seasonal basis when large numbers of hikers utilize its main tributary as a route into the back country. The stream also is an important spawning ground for the land-locked red salmon which die after spawning and contribute to the stream's fertility (see Section XII).

When stream courses are altered, as was the case with Third Creek when it was diverted to make way for a golf course during the Incline Village development, a large nutrient release results. Figure 35 illustrates the biostimulatory effect of this stream to Lake Tahoe waters in comparison with three other streams following the rechannelization. This represented the greatest amount of stimulation recorded from any stream bioassayed in the basin and provides clear evidence of the serious nature of major watershed manipulations in speeding the cultural eutrophication of the lake.

It is very probable that with major portions of sewage now being diverted from the basin, the dramatic increase in in situ lake primary productivity evidenced during the course of this study (see Section VI) is largely due to mechanical disruption of the watershed associated with soil exposure and vegetation loss resulting from construction of new roads and subdivisions. Once the basin is "built up" to its planned capacity, this kind of input should gradually decline. That stabilization nutrient input takes considerable time is indicated by the still potent fertilization from the Heavenly Valley Creek area which was used as a land disposal site for treated sewage effluent (see Land Disposal subsection).

LIMNOLOGICAL STUDIES AND REMOTE SENSING OF THE UPPER TRUCKEE RIVER SEDIMENT PLUME IN LAKE TAHOE, CALIFORNIA-NEVADA

(This work is published in Remote Sensing of Environment, by Charles R. Goldman, Robert C. Richards, Hans W. Paerl, Institute of Ecology,

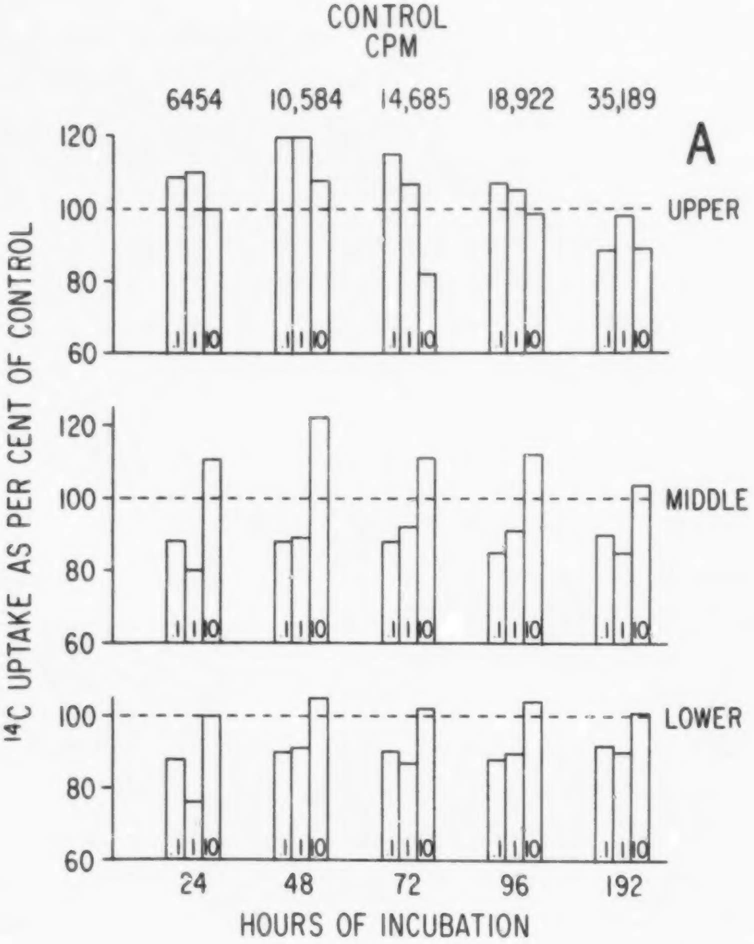


Figure 34a. Bioassay of Taylor Creek water additions to Lake Tahoe water. Significant increase in biostimulation was noted from winter (A) to spring (B).

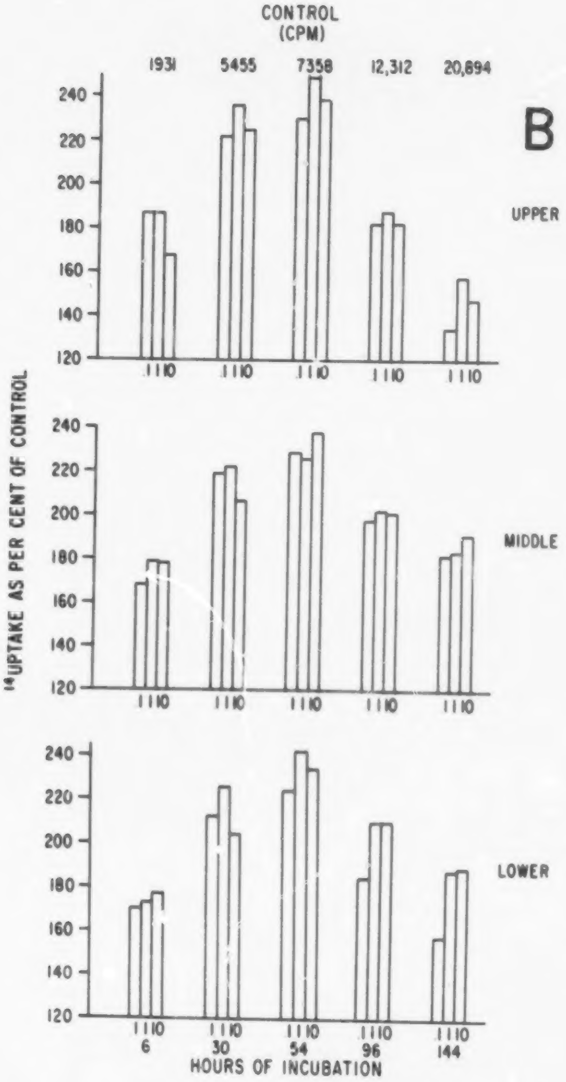


Figure 34b. Bioassay of Taylor Creek water additions to Lake Tahoe water. Significant increase in biostimulation was noted from winter (A) to spring (B).

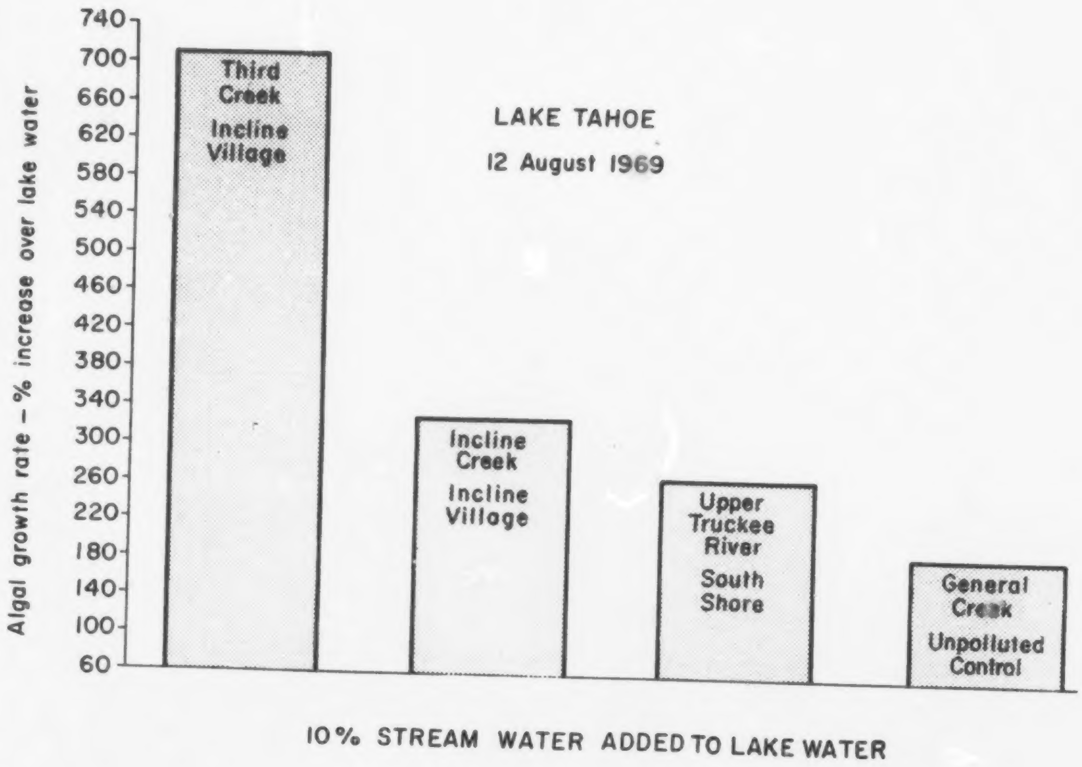


Figure 35. Biostimulation of Lake Tahoe water from a 10% addition of four of its tributaries. Highest biostimulation was measured by Third Creek following disturbance of its watershed. General Creek, which drains an undisturbed area, was used as a control.

University of California, Davis and Robert C. Wrigley, Verne R. Oberbeck, and William L. Quaide, Space Science Division, NASA-Ames Research Center, Moffett Field, California).

Introduction

Accelerated eutrophication of Lake Tahoe, an oligotrophic subalpine lake, has been evident from casual observation of algal growth in shallow water and measured increases in primary productivity and algal biomass of phytoplankton (free-floating algae) as well as periphyton biomass (attached algae) (Goldman and Armstrong 1969; Goldman 1970a; and Goldman, Moshiri, and Amezaga 1972). These authors also investigated tributary streams, the major source of nutrient enrichment, and demonstrated stimulatory effects of stream water on growth of the natural phytoplankton population in Tahoe water. In addition, in situ sampling of transects toward (the mouth of) the Upper Truckee River, the major tributary, indicated the increases in both heterotrophic (bacterial) activity and primary productivity as the stream mouth was approached (Paerl and Goldman 1972a). These results, coupled with evidence of recently doubled sediment contribution to the Upper Truckee River from man-made disturbances on its watershed (State of California Resources Agency 1969), point strongly to siltation as an increasingly important and continuing cause of lake enrichment. (This is particularly true now that treated sewage effluent is exported from most of the lake basin and is considered less of a threat to water quality than it was in the past).

The influence of major tributaries on lakes and rivers has long been studied (Hutchinson 1957, p. 295). Water masses peculiar to an inflowing river or stream have been traced and identified in the receiving water body through measurement of various parameters. Movement of the Rhine River through Lake Constance (Numann 1938), the Rhone through

Lake Geneva (Dussart 1948), and the Colorado through Lake Mead (Anderson and Pritchard 1951) are all cases in point. The biological influence of tributaries on lake fertility has been evaluated by bioassay in a number of Alaskan and Californian lakes (Goldman 1964). Temperature, oxygen, light transmission, dyes, sediment load, conductivity, and chemical and biological changes have all been utilized to some extent. Few studies have, however, coupled the use of limnological field methods with high resolution aerial photography to provide an overall view of the process. In this study, simultaneous photography and water sampling have provided a nearly instantaneous measure of variation in biological productivity and physical changes in the lake under the influence of its major tributary.

A joint study by Ames Research Center (NASA) and the University of California, Davis was begun in early 1971 to document the influence of the Upper Truckee River sediment plume on eutrophication of Lake Tahoe. The study area is shown in Figure 36. The major objective was to determine if high resolution aerial photography could be used to correlate location of the plume with biological, physical, and chemical conditions measured in the water mass and indicate the value of photography in defining plume limits. Another objective was to investigate the relationship between siltation and the process of eutrophication. Lake Tahoe is particularly appropriate for this study, because the water is extremely clear and the plume varies seasonally in volume and intensity. Spring snowmelt water entering the Upper Truckee River from the highly urbanized South Lake Tahoe Valley area produces the most significant sediment plumes observed in the lake.

Methods

Sampling Time Selection -

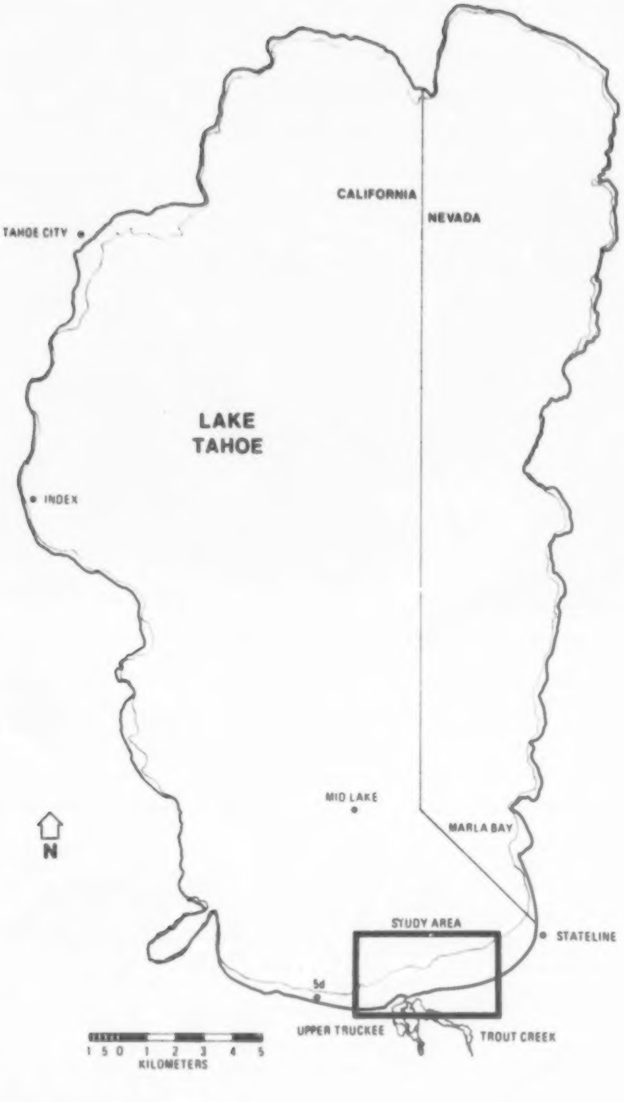

CALIFORNIA
NEVADA
TAHOE CITY
LAKE TAHOE
INDEX
MID LAKE
MARLA BAY
N
STUDY AREA
STATELINE
5d
UPPER TRUCKEE
TROUT CREEK
1 5 0 1 2 3 4 5
KILOMETERS

Figure 36. Map of Lake Tahoe indicating the Upper Truckee transect study area. The index, mid-lake, and 5d stations not shown on Figures 38-42 are shown here. The thin line around the lake periphery indicates 6 m depth.

Observation of changing meteorological conditions in northern California-Nevada and on-site reconnaissance was used to select sampling dates during the 1971 runoff. Sampling was scheduled to include a variety of runoff stages, encompassing low and peak flows. Past stream flow records for the Upper Truckee River were combined with meteorological data, primarily air temperatures, to predict runoff development. It was also necessary to have favorable conditions for aerial photography over water: clear skies, low windspeed (<10 kt), and moderate sun angle (30-50° above the horizon). The latter was accomplished by conducting the photography during the early morning or late afternoon. Lack of favorable conditions prevented sampling during May.

Field Methods -

While aerial photographs were being taken, samples for chemical analysis, biological activity, and physical characteristics of the plume area were collected along transects radiating from the Upper Truckee River mouth. Shallow water samples were taken near the bottom, deep water samples at 20 m. A fast boat usually made collection possible during a three-hour period. Station location was achieved by sighting on-shore landmarks and prominent bottom features. Samples were transported in darkened ice chests to the laboratory. Additionally, on-site measurements at the twenty stations usually included light transmission, temperature, Secchi disk measurements, and field notes on visual conditions of the water.

Primary (algal) productivity samples were transferred to 125 ml Pyrex® bottles, injected with ^{14}C-bicarbonate, and incubated in situ for four hours at 2-m depth from a lakeside pier (Goldman 1963, Goldman and Carter 1965). Morning samples were incubated the same afternoon. The 20 June afternoon samples were held overnight in the dark at lake surface temperature and incubated the following morning.

Heterotrophic (bacterial) activity samples were transferred in parallel to 125 ml opaque Pyrex® bottles. Heterotrophic assimilation of 2-^{14}C-acetate was measured by adding a trace amount (10 ng acetate$\cdot$l^{-1}) of carbon-14 labeled substrate to each water sample. Incubation was done in a darkened incubator with rotator. Incubation temperatures were held close to sampling temperatures. Assimilation rates were compared throughout the sampling period. In earlier work (Paerl and Goldman 1972a), assimilation of acetate was shown to be largely due to bacteria in Lake Tahoe and acetate concentrations in the lake (derived from gas chromatographic analyses and kinetic plots) varied from 1 to 10 μg acetate$\cdot$l^{-1}. (Micro-autoradiography was employed in the earlier study to demonstrate bacterial uptake and absence of algal uptake of ^{14}C-acetate at the substrate concentration used in experiments reported here.)

Incubation of heterogenous samples taken at depths ranging from 0.5 to 20.0 m and differing environmental surroundings (light, temperature, nutrients, etc.) do not give absolute in situ values of primary productivity and heterotrophic activity. The values are an index of the ability of different phytoplankton and bacterial populations to respond to stimuli under similar, measurable conditions. Both sets of samples were filtered at low vacuum on 25 mm, 0.45 μm filters (HA Millipore®) immediately after incubation. Air-dried filters were counted with a Geiger-Muller ultrathin window counter and scaler (Nuclear-Chicago®), calibrated with gas phase (Goldman 1968a), or a Beckman® LS-100 liquid scintillation counting system.

The remainder of the water sample was divided into smaller containers for determination of dissolved inorganic carbon (DIC), sediment content, water chemistry, and phytoplankton identification and enumeration. Dissolved inorganic carbon, composed mainly of HCO_3^-, was determined immediately by infrared analysis using $NaHCO_3$ standards (Armstrong, Goldman, and Fujita 1971). Water chemistry samples were immediately analyzed or preserved by freezing. Phosphate, nitrate, and iron analyses were done according to procedures for microgram quantities (Strickland and Parsons 1968), with modifications by Fujita (see Appendix E).

Phytoplankton samples preserved in Lugol's solution were filtered (0.45 μm) and the filters oil-cleared. Phytoplankton were counted by species from a filter area large enough to allow less than 10% error in total count. A Wild® inverted microscope equipped with an image-splitting eyepiece for cell volume (biomass) calculations was used. Primary productivity, phytoplankton numbers, biomass, and correlation coefficients were computed using a Burroughs® 6700 computer. Suspended sediment samples were filtered through 47 mm, 0.8 μm filters (AA Millipore®) and dried for 24 hours at 110°C. Filter weight, corrected for an average loss on drying, was subtracted from the weight of the filter with its retained sediment.

Photographic Coverage -

The Upper Truckee River sediment plume was photographed at each sampling time to yield overlapping coverage about 20 km^2 at a scale of 1:20,000. Each photographic mission used a Kargl K3B camera of 225 mm x 225 mm format and either a 305 mm or 210 mm focal length lens. Kodak® 2448 color film was developed to a positive transparency. On one mission, multispectral and color photographs were taken simultaneously to evaluate application of multispectral photography to sediment plume study. An International Imaging Systems MK 1 multispectral camera recorded four wavelength band images on different squares of the same 225 mm x 225 mm negative. The scale was 1:42,000. Wratten® 25, 57a, and 47b filters were used on lenses photographing red, green, and blue wavelengths, respectively, along with special infrared blocking filters. Only a

Wratten^{R} 88a filter was used on the lens photographing near infrared. Multispectral film was developed to a negative and positive transparencies were used for sediment plume study.

Photographic analysis involved converting photographs into line drawings and determining the extent of various units of differing visual contrast within the plume. Silt-laden river water entering the lake from the Upper Truckee River contrasts strongly with clear lake water and the shallow shelf bottom. As the river water intrudes further into the lake, various water masses develop which change in position and visual contrast with time. Their boundaries can usually be delineated with little difficulty. They can be mapped as discrete areal units and assigned density values representing degrees of contrast. Beyond the shallow shelf (6 m), the bottom slopes precipitously. Contrasts are still visible, but estimated density values are less accurate. Units beyond the shelf are often extensions of near-shore plume units which allow successful extrapolation. Four or five values of contrast density were assigned in each plume study. Heavily silt-laden river water was given a value of "1". Higher numbers were assigned as the visual contrast against the shelf bottom decreased. Contrast values are valid only for relative comparisons at a given time and are only generally similar for different sampling dates. In one case it was necessary to assign the values "1a" and "1b", because two areal units had similar values of contrast but differed in color. Line drawings were superimposed on a modified U.S.C. and G.S. chart 5001 showing sampling stations, shoreline, and the offshore shelf margin.

Results

Development of the Sediment Plume -

Four days were selected for study: 29 March, 12 April, 7 June, and 20 June. These represented a variety of snowmelt runoff stages during

1971. On 20 June photographs and water samples were taken in both early morning and late afternoon with photogrphic coverage by both color and multispectral cameras in the morning. Daily streamflow data for the Upper Truckee River and Trout Creek were supplied by the Water Resources Division of the Gological Survey in Carson City (Fig. 37A). The 29 March and 12 April studies occurred during early stages of snowpack melting while those of 7 June and 20 June bracket peak melt runoff. Also shown are daily maximum and minimum air temperatures at Tahoe Valley airport (Fig. 37B) and precipitation data taken at Tahoe City (Figs. 37C,D). Tahoe City is not in the Upper Truckee River watershed, but it is the only precipitation station in the Tahoe basin.

Figure 37A shows that from October 1970 to late March 1971, runoff is generally very low (daily average about 1 $m^3 \cdot sec^{-1}$). However, some restricted periods of high runoff do occur. Runoff peaks on 25 November, 17 January, and 26 March were due to heavy rain and/or snow that melted soon after falling.

Figures 37C,D show total precipitation at Tahoe City was high on 25 November and 26 March, but snowfall was low compared to other days. This implies conditions of alternating rain and snow with most of the precipitation as rain. On 17 January a total of 0.8 cm precipitation fell despite no record of snowfall. Thus, isolated peaks in runoff during low flow periods from October 1970 to late March 1971 were produced by heavy rains and rapidly melting snow. The 29 March study was shortly after the day of maximum yearly precipitation at Tahoe City. On 26 March, the precipitation consisted mostly of rain. It is likely that this rain had a pronounced effect on plume formation three days later.

Spring melting of the Tahoe basin snowpack produced large runoff in the Upper Truckee River and Trout Creek from late March to late June

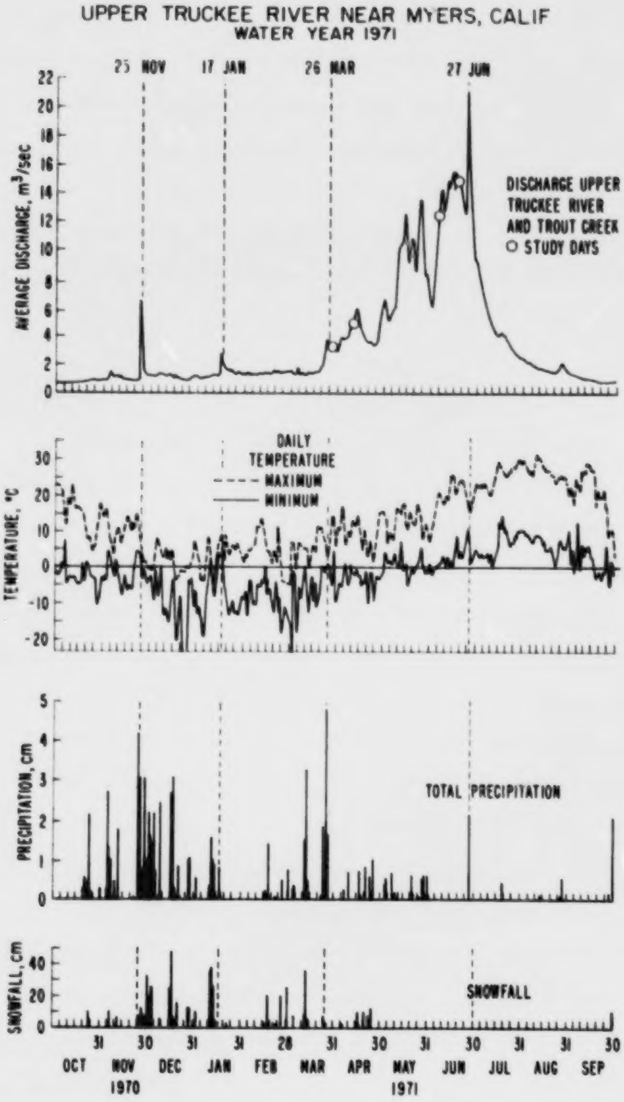
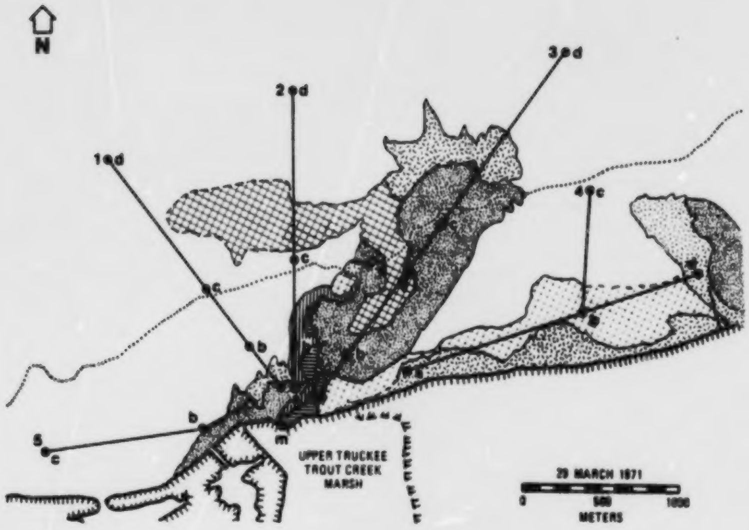


Figure 37. Seasonal variation in stream flow and meteorological conditions in the Upper Truckee River watershed during the 1970-71 water year.

(Fig. 37A). Diurnal fluctuations in runoff rate occurred due to insolation and warmer daytime air temperatures followed by cooler night air temperatures. Figure 37B shows that when daily minimum temperatures consistently exceeded freezing, runoff became large and flow variations followed daily maximum temperature fluctuations. When daily maximum temperatures exceeded 15°C, runoff neared its maximum. A major cooling trend in late May reduced runoff more than 50% although daily minimum temperatures did not drop.

There appears to be increasing sediment plume development associated with increasing runoff of melting snowpack. This would be expected due to increased displacement of lake water by turbid river water. Figures 38-42 show maps of each sediment plume outline and various units of differing visual contrast densities within the plumes. The 29 March and 12 April plumes are confined to the lakeshore east of the river mouth and extend northerly to just beyond the shallow shelf edge. Both plumes of 20 June, near maximum runoff, extended far into the lake (>3 km) and along the eastern shore as far as Marla Bay, 8 km from the river mouth (Fig. 36). We have no explanation for the fact that the 7 June plume occurred during high runoff, but had the smallest total outlined area. It contained the largest extent of highly contrasted areal units (density values 1 and 2) of all morning plumes. Total mapped areas of morning plumes are not a strong function of runoff even excluding the 7 June plume: a 40% increase in plume area occurred from 29 March to 20 June while runoff increased 400%. Multi-spectral photographs of the 20 June morning plume (Fig. 43) show much greater plume area, especially to the north, than color photographs and indicate observational difficulties with color film.

Figure 43 also shows differing responses to the plume among the spectral bands. Blue band response delineates the plume envelope well in both shallow and deep water, but loses detail in dense plume areas; the

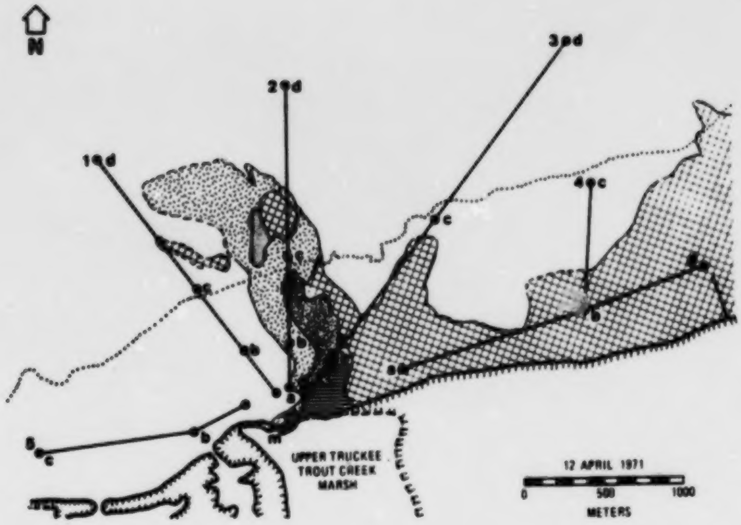

N
1d
2d
3d
4c
c
b
5
c
m
UPPER TRUCKEE
TROUT CREEK
MARSH
29 MARCH 1971
0
500
1000
METERS

STATION	SUSPENDED SEDIMENT	DIC	PRIMARY PRODUCTIVITY
UT MOUTH	7.5	5.5	30
1A	0.8	10.8	44
1B	0.4	11.2	3
1C	0.3	11.0	18
1D	0.5	10.5	30
2A	0.6	10.0	22
2B	2.5	9.6	22
2C	0.6	9.8	20
2D	0.1	9.9	19
3A	8.8	7.5	42
3B	5.9	7.4	24
3C	33.5	9.7	42
3D	0.1	9.8	29
4A	17.5	9.8	100
4B	4.2	8.0	47
4C	0.6	9.5	27
4D	–	–	–
5A	–	–	–
5B	–	–	–
5C	–	–	–
5D	0.3	9.7	29
Mid Lake Index	0.2	10.2	16
	0.3	9.6	8

VISUAL PLUME DENSITY

m	RIVER MOUTH	▨	1 a/b (MOST DENSE)
●	SAMPLING STATION	▩	2
┄	SHELF MARGIN	☐	3
╥╥	SHORE LINE	▒	4 (LEAST DENSE)

Figure 38. The Upper Truckee River sediment plume for 29 March 1971. Values of suspended sediment (mg/l), dissolved inorganic carbon (DIC) (mg/l), heterotrophic activity (μg acetate/m^3/hr of assimilation), and primary productivity (mg C/m^3/hr of incubation x 10^{-2}) are also given. These same values are also given in Figures 39-42.

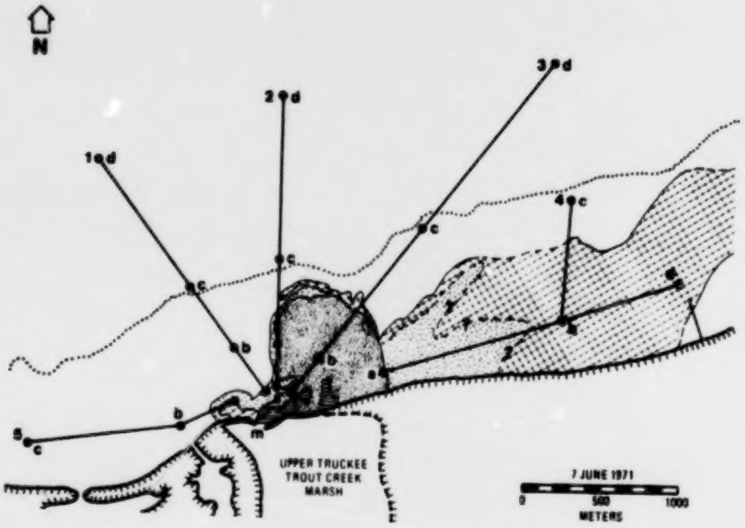

N
1 d
2 d
3 d
4 c
c
b
a
5 c
b
m
UPPER TRUCKEE TROUT CREEK MARSH
12 APRIL 1971
0
500
1000
METERS

STATION	SUSPENDED SEDIMENT	DIC	HETEROTROPHIC ACTIVITY	PRIMARY PRODUCTIVITY
UT MOUTH	21	5.5	150.6	24
1A	0.5	10.8	5.7	<1
1B	0.4	11.2	5.3	12
1C	0.4	11.0	5.5	15
1D	0.5	10.5	2.2	12
2A	0.4	10.0	21.2	6
2B	0.3	9.6	7.5	2
2C	0.4	9.8	8.6	11
2D	0.3	9.9	3.3	14
3A	7.4	7.5	188.9	61
3B	4.3	7.4	152.6	20
3C	0.3	9.7	4.4	9
3D	0.6	10.1	4.8	25
4A	2.3	9.8	50.4	18
4B	5.8	8.0	48.2	19
4C	0.3	9.5	5.3	16
4D	1.6	9.5	95.5	22
5A	1.5	10.6	5.9	8
5B	0.7	9.9	8.2	6
5C	0.6	9.9	4.4	5
5D	0.3	10.0	3.5	9
Mid Lake	0.1	10.2	–	18

VISUAL PLUME DENSITY

m RIVER MOUTH ▤ 1 (MOST DENSE)
● SAMPLING STATION ▩ 2
┈ SHELF MARGIN ▒ 3
ᵚ SHORE LINE ▦ 4
☐ 5 (LEAST DENSE)

Figure 39. The Upper Truckee River sediment plume for 12 April 1971,


N
1d
2d
3d
c
b
a
4c
5
c
m
1
2
UPPER TRUCKEE TROUT CREEK MARSH
7 JUNE 1971
0
500
1000
METERS

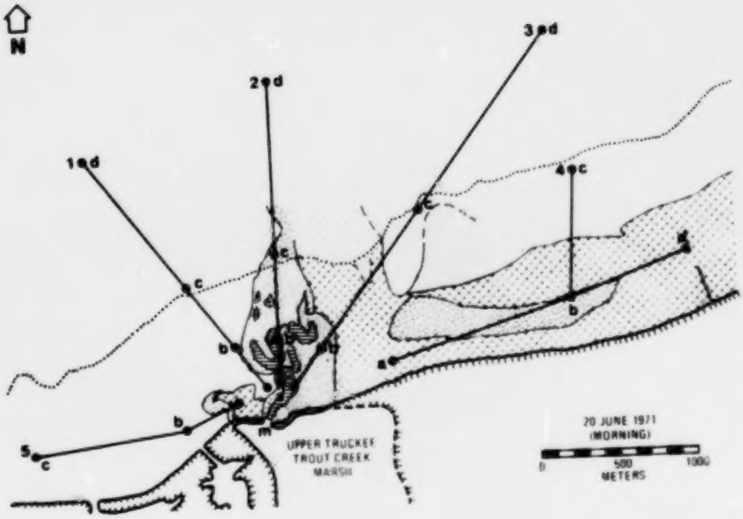
STATION	SUSPENDED SEDIMENT	DIC	HETEROTROPHIC ACTIVITY	PRIMARY PRODUCTIVITY
UT MOUTH	14.7	2.1	572.4	67
1A	1.1	9.2	86.6	44
1B	0.2	9.6	9.8	44
1C	0.2	9.6	10.8	15
1D	0.7	9.7	13.8	19
2A	0.3	7.7	174.1	44
2B	0.2	9.3	11.8	33
2C	0.3	9.7	12.9	33
2D	0.2	9.4	5.4	6
3A	6.2	5.5	327.7	54
3B	0.8	8.0	241.7	30
3C	0.6	9.4	22.6	38
3D	0.2	9.6	10.8	38
4A	1.6	6.4	324.4	68
4B	1.0	7.7	148.4	42
4C	0.4	9.3	5.7	27
4D	0.7	8.4	347.0	56
5A	0.6	9.4	50.2	57
5B	0.5	10.5	18.2	6
5C	0.4	10.2	24.7	42
5D	0.2	10.1	7.9	38
Mid Lake	0.6	10.0	4.7	26

VISUAL PLUME DENSITY

m RIVER MOUTH
● SAMPLING STATION
┈ SHELF MARGIN
ᚗ SHORE LINE

▤ 1 (MOST DENSE)
▩ 2
▨ 3
▧ 4 (LEAST DENSE)

Figure 40. The Upper Truckee River sediment plume for 7 June 1971.


N
1 d
2 d
3 d
4 c
5 c
c
b
a
m
UPPER TRUCKEE TROUT CREEK MARSH
20 JUNE 1971 (MORNING)
0
500
1000
METERS

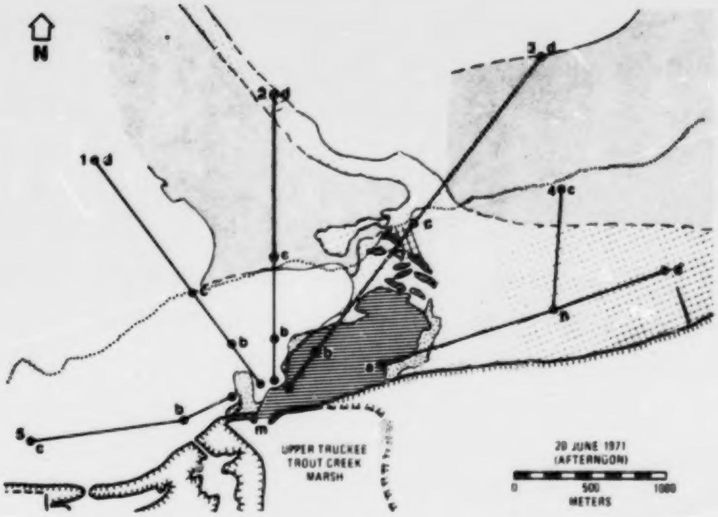
STATION	SUSPENDED SEDIMENT	DIC	HETEROTROPHIC ACTIVITY	PRIMARY PRODUCTIVITY
UTM	8.4	3.0	2530.8	28
1A	0.4	8.3	64.8	17
1B	0.3	6.6	70.5	19
1C	0.1	8.6	52.1	13
1D	0.1	8.7	27.4	16
2A	2.1	7.6	651.8	21
2B	6.1	5.8	1299.9	19
2C	0.3	8.6	62.5	9
2D	0.1	8.6	38.7	18
3A	8.9	3.8	36.8	33
3B	0.5	8.3	7868.4	32
3C	0.2	9.0	412.4	20
3D	0.1	8.6	80.8	9
4A	0.7	7.9	752.9	19
4B	0.5	8.1	274.8	18
4C	0.2	8.8	50.7	17
4D	0.4	8.2	274.1	36
5A	2.6	6.8	1059.3	20
5B	0.4	4.6	269.9	16
5C	0.2	8.4	70.8	9
5D	0.3	8.3	67.8	13
Mid Lake	0.1	8.6	28.9	9
Index	0.0	8.4	59.8	24

VISUAL PLUME DENSITY

m RIVER MOUTH
● SAMPLING STATION
...... SHELF MARGIN
━━ SHORE LINE

▤ 1 (MOST DENSE)
▩ 2
▦ 3
▨ 4
☐ 5 (LEAST DENSE)

Figure 41. The Upper Truckee River sediment plume for the morning of 20 June 1971.


N
1 d
2 d
3 d
4 c
5 c
b
c
e
m
UPPER TRUCKEE
TROUT CREEK
MARSH
20 JUNE 1971
(AFTERNOON)
0
500
1000
METERS

STATION	SUSPENDED SEDIMENT	DIC	HETEROTROPHIC ACTIVITY	PRIMARY PRODUCTIVITY
UTM	9.5	2.6	2311.3	74
1A	0.7	8.8	30.9	19
1B	0.3	9.0	33.3	12
1C	0.3	9.0	34.1	32
1D	0.4	9.0	18.0	17
2A	0.7	9.0	46.6	17
2B	0.6	9.2	30.1	20
2C	1.3	9.0	43.0	17
2D	0.3	9.2	28.0	21
3A	4.7	6.0	1183.1	48
3B	2.7	7.8	623.8	42
3C	0.6	8.9	65.4	23
3D	0.5	8.9	19.6	14
4A	4.1	4.4	2437.4	27
4B	0.7	7.9	182.6	21
4C	0.5	8.6	88.5	28
4D	0.8	8.0	282.4	35
5A	3.2	7.5	678.7	38
5B	0.6	8.8	44.5	13
5C	0.2	8.7	56.8	13
5D	0.2	8.5	55.5	22
Mid Lake	-0.1	8.6	18.8	13
Index	0.2	9.1	47.2	23

VISUAL PLUME DENSITY

m RIVER MOUTH
● SAMPLING STATION
— SHELF MARGIN
┬┬┬ SHORE LINE

▤ 1 (MOST DENSE)
▨ 2
▒ 3
▦ 4
☐ 5 (LEAST DENSE)

Figure 42. The Upper Truckee River sediment plume for the afternoon of 20 June 1971.

effect appears to be a reduction of upwelling light by scattering and/or absorption. Against the bright, shallow shelf, the green band shows less reduction of upwelling light than the blue and provides some interior plume structure. In deep water, denser plume areas appear bright in green light against a dark background due to reflection from suspended sediment. Reflection predominates in very dense plume areas in the red band and provides more internal structure, but in somewhat less dense plume areas sediment reduces upwelling red light creating a dark area against the shelf. Thus, there is a gradation between reflection and absorption which is dependent upon sediment concentration. No infrared light derives from either clear or sedimented areas due to a large attenuation coefficient in water for this band and an apparent lack of significant amounts of sediment at the surface.

Relationship Between Aerial Photographic Interpretations and Aquatic Measurements -

Sediment plume density maps based on relative visual contrasts of adjacent water masses are in good agreement with water property measurements and field observations as detailed below.

Suspended sediment - Visually dense plume units near the river mouth contain the most suspended sediment whereas less dense, more extensive units contain less sediment (Figs. 38-42). Sediment from all plumes consists primarily of silt-size mineral grains of feldspar, mica, quartz, and hornblende in order of decreasing abundance according to X-ray diffraction and microscopic analyses. These minerals comprise a large portion of bottom sediments in this area of the lake (Court, Goldman, and Hyne 1972). Combustible material (organic matter) is generally present in amounts less than 20% in weight. Inspection of filtered sediment residues revealed that samples from dense plume units near the mouth are generally coarser grained than those from plume units of lesser visual density. This indicates that dispersion of

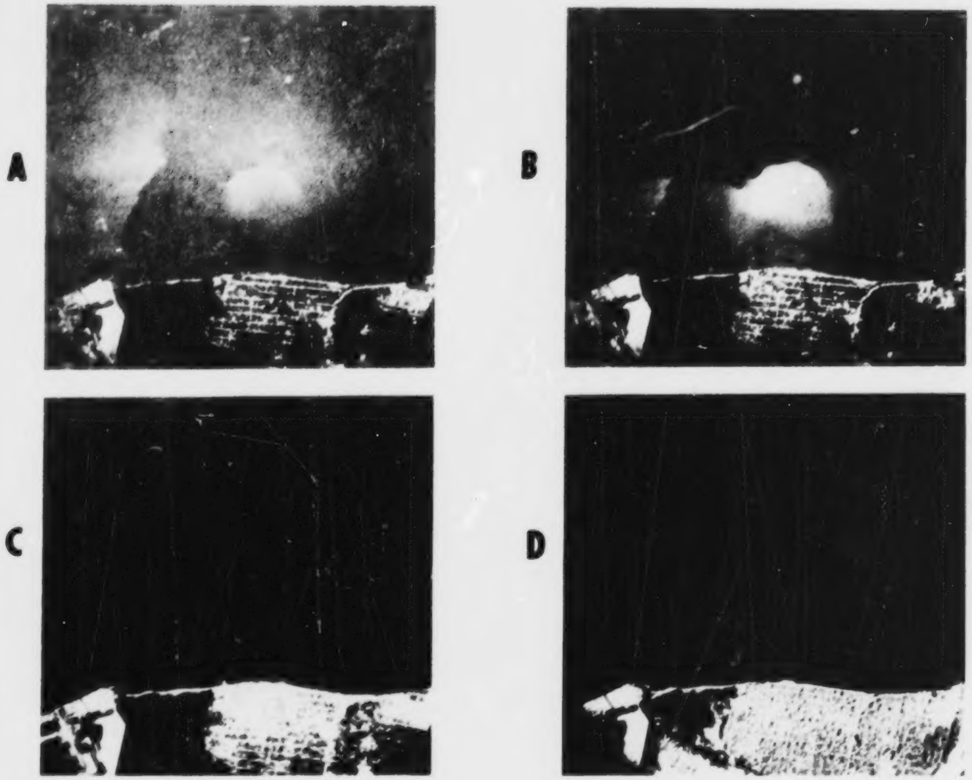


Figure 43. Multispectral photograph of the Upper Truckee River sediment plume for the morning of 20 June 1971. Blue band (A), green band (B), red band (C), infrared band (D).

sediment from the river mouth is, in part, a function of grain size and implies that photographically defined units are units of differing suspended sediment size as well as quantity.

Water chemistry, dissolved inorganic carbon (DIC) - In all plume transects, except that of 29 March, there appeared to be a strong relationship among increasing plume density, increasing suspended sediment, and decreasing DIC; Table 27 shows correlations at confidence levels above 99.9%. The river mouth always had the lowest DIC. Values increased in irregular fashion away from the mouth in a way highly dependent upon plume configuration. At stations where isolated lenses of turbid water occurred, DIC was lower. This measurement appears to have promise as a water mass marker where differences between river (3-5 mg $C \cdot l^{-1}$) and lake (8-10 mg $C \cdot l^{-1}$) are great enough.

Water chemistry, nutrients - Three of the biologically more important nutrients (nitrate, phosphate, iron) were sampled and analyzed from all studies except the first two, which did not include iron analyses. Results show that inflowing river water is consistently nutrient enriched relative to mid-lake and index station waters; iron by a factor of 25, nitrate and phosphate by factors of 10. There is a spotty relationship between nutrients and either plume density values, suspended sediment, or DIC. Table 27 shows nutrients correlate well with these parameters for the first two studies, but only moderately or poorly for other studies. Sample sites west of the plumes consistently had nutrient contents similar to mid-lake. Samples from regions directly influenced by inflowing river water had nutrient contents intermediate between river mouth and mid-lake waters. Iron and phosphate concentrations at almost all stations north and east of the river mouth increased significantly from morning to afternoon on 20 June. Nitrate concentration increased to a lesser extent. The greatest increases occurred at station 4b: from 18 to 40 $\mu g \cdot l^{-1}$ iron, 17 to 32 $\mu g \cdot l^{-1}$ phosphate, and 6 to 10

$\mu g \cdot l^{-1}$ nitrate. This nutrient change paralleled photographically observed eastward movement of the plume.

Temperature and light measurements - Temperature readings were not taken during March, but during all other morning samplings river mouth temperatures were lower than any lake station. They increased during the season from 3.0°C on 12 April to 8.8°C on 20 June while surface temperatures in clear lake water increased from 5-6°C to 10-12°C. Plume area surface temperatures directly northeast of the river mouth were always intermediate between those of the mouth and clear water. Vertical temperature gradients in this area indicate that simple density gradient flow occurred. Dense plume units farther from the river mouth had near surface temperatures approximately 1°C higher than clear water, suggesting that solar heating of suspended sediment particles was responsible, in part, for water mass warming. Temperatures in less dense plume units along the shore east of the river mouth were consistently 2-3°C higher than those in similarly shallow clear water to the west. This is consistent with a solar heating mechanism. Such warming created a double-valued function of temperature vs. other parameters and precluded good simple correlations. Table 27 shows no consistent temperature correlation with plume density, suspended sediment, or DIC for morning plumes.

The temperature of river mouth water reached 15.5°C during the afternoon of 20 June, considerably higher than the morning (8.8°C) and higher than any lake station at the time of sampling (12-15°C). Again, stations to the northeast had temperatures intermediate between the river mouth and clear water. Although some vertical mixing of river and lake waters occurred, vertical temperature gradients indicate that river water intrusion took place primarily by surface flow over cooler, more dense lake waters. Surface temperatures in tenuous plume units along the eastern shore and beyond the shelf to the north were higher than temperatures in plume units nearer the mouth. The former approximate the

TABLE 27. SIMPLE CORRELATION COEFFICIENTS FOR SEDIMENT PLUME VARIABLES[1]

DATE	VARIABLE	SED.	DIC	HET.	PPR	NO_3	PO_4	FE	LIGHT	TEMP.	CELLS	BIOMASS
	PLUME DENSITY UNITS	-0.464				-0.712	-0.730					
	SUSPENDED SEDIMENT				0.556		0.709					
29 MARCH 1971	DIC					-0.686	-0.673					
(17 DEGREES OF FREEDOM)	PRIMARY PRODUCTIVITY						0.597					0.523
	NO_3 - N						0.860					
	PO_4 - P											
	NO. CELLS · VOLUME^{-1}											0.490
	PLUME DENSITY UNITS	-0.819	0.845	-0.891	-0.625	-0.844	-0.802		0.709			
	SUSPENDED SEDIMENT		-0.907	0.898	0.686	0.965	0.921		-0.603			0.448
	DIC			0.872	-0.540	-0.931	-0.892		0.630			0.462
12 APRIL 1971	HETEROTROPHIC ACTIVITY				0.733	0.893	0.898		-0.615			0.544
(17 DEGREES OF FREEDOM)	PRIMARY PRODUCTIVITY					0.570	0.549					
	NO_3 - N						0.902		0.604	-0.500		
	PO_4 - P								-0.645			0.610
	LIGHT PENETRATION											
	SURFACE TEMPERATURE										0.457	
	NO. CELLS · VOLUME^{-1}											0.630
	PLUME DENSITY UNITS	-0.642	0.831	-0.818	-0.673				0.722			
	SUSPENDED SEDIMENT		-0.873	0.783					-0.682	-0.704		
7 JUNE 1971	DIC			-0.928	-0.660	-0.580	-0.432	-0.574	0.733			
(20 DEGREES OF FREEDOM)	HETEROTROPHIC ACTIVITY				0.695	0.483		0.487	-0.819			
	PRIMARY PRODUCTIVITY								-0.550			
	NO_3 - N						0.840	0.838				
	PO_4 - P							0.842				
	FE											
	LIGHT PENETRATION											
	SURFACE TEMPERATURE											
	NO. CELLS · VOLUME^{-1}											0.678

Table 27. Cont'd.

Date	Variable	Sed.	DIC	Het.	PPR	NO_3	PO_4	Fe	Light	Temp.	Cells	Biomass
	Plume Density Units	-0.766	0.755	-0.619	-0.561			-0.730	0.655			-0.581
	Suspended Sediment		-0.981	0.416	0.493			0.599	-0.704	-0.579	0.624	0.811
20 June 1971	DIC			-0.495	-0.513			-0.556	0.661	0.601	-0.660	-0.854
Morning	Heterotrophic Activity				0.508	0.446		0.524				0.577
	Primary Productivity											
(21 Degrees of freedom)	NO_3 - N						0.474	0.552				0.440
	PO_4 - P							0.689	-0.447			
	Fe								-0.631		0.443	0.623
	Light Penetration									0.636		-0.515
	Surface Temperature										-0.442	-0.544
	No. Cells · Volume^{-1}											0.867
	Plume Density Units	-0.752	0.776	-0.796	-0.695	-0.689	-0.456	-0.609	0.699	-0.620	-0.510	-0.576
	Suspended Sediment		-0.941	0.898	0.873	0.615		0.444	-0.713	0.469	0.538	0.890
20 June 1971	DIC			-0.970	-0.791	-0.605			0.688	-0.489		-0.780
Afternoon	Heterotrophic Activity				0.721	0.572			-0.723	0.472		0.682
	Primary Productivity					0.683			-0.688		0.510	0.831
(21 Degrees of freedom)	NO_3 - N						0.584	0.734	0.441	0.513	0.610	0.640
	PO_4 - P							0.919		0.674		
	Fe									0.715	0.460	0.443
	Light Penetration											0.576
	Surface Temperature											
	No. Cells · Volume^{-1}											0.637

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[1] Direct and inverse relationships are indicated by positive and negative values respectively. Simple correlation coefficients near zero imply no correlation whereas simple correlation coefficients near 1.000 or-1.000 imply high direct or inverse correlations, respectively. Plume density units are such that low numbers correspond to high plume density. Thus, any relationshif that would be direct in terms of plume density appears as an inverse one in terms of plume density units and vice versa. Confidence levels for correlation coefficients are indicated thusly: 0.xxx => 95%, 0.xxx => 99%, and 0.xxx = 99.9%. Simple correlation coefficients below 95% confidence level have been omitted for convenience.

mouth temperature. Warming of distal plume units again points to solar heating of suspended sediment. Correlations of temperature with a number of variables in Table 27 improved markedly over morning plumes possibly because high mouth temperatures created less pronounced double-valued functions.

Photometric measurements of light penetration were reduced to relative values to compare penetration with visual plume density. Relative values at each turbid water station were determined by dividing percent light penetration at the deepest measurement by percent light transmission at that depth in clear water. Such values consistently correlate well with plume densities, suspended sediment, and DIC (Table 27). Clear water stations always had high relative light penetration values (0.7-1.0), while stations in dense plume units (1 or 2) always had low values (0.1-0.6). Stations with intermediate plume density values (3,4, or 5) usually had relative light penetration close to clear water. In many cases, such stations were indistinguishable. Similarly, plume units 1 and 2 could not be distinguished one from another. It appears color aerial photographs can be used more successfully than light penetration values to distinguish various degrees of turbidity.

Secchi disk readings could be made only in clear water deeper than 20 m or in very turbid shallow water. Disk readings could not be taken where the bottom was visible. Stations beyond the shelf had lower readings (18 to 34 m) than mid-lake stations (26 to 40 m).

Heterotrophic activity - It has been demonstrated that the influence of the Upper Truckee River upon bacterial growth in Lake Tahoe is pronounced (Paerl and Goldman 1972a). Growth has also been shown to increase from winter to summer. This is well illustrated by Figures 39-42 where heterotrophic acetate assimilation in μg acetate$\cdot m^{-3}\cdot hr^{-1}$ is given for each station. Heterotrophic activity varied over two orders of magnitude and correlated excellently with plume density, suspended sediment, DIC, and light penetration (Table 27). Plcts of heterotrophic activity vs. plume density units show a consistently strong relationship. Increased photographic capability enhances the spatial relationship between measured microbial activity and photographically detected water masses noted earlier (Paerl and Goldman 1972a). Although values were low during April, the influence of the inflowing water was still readily detectable. Assimilation values were higher at the river mouth, directly north in the heart of the plume, and along the eastern shelf. June transects show a similar strong relationship between heterotrophic activity and plume shape and density. Transect assimilation values were higher. The double sampling on 20 June registered peak values during the sampling period and showed a distinct shift eastward in the afternoon.

Primary productivity - Phytoplankton carbon assimilation rates relate to changes in plume density and configuration in a more irregular fashion than does bacterial activity. Still, primary productivity increased in areas influenced by the plume to the north and east of the river, but remained low in clear water to the west. Higher values of primary productivity were observed in 1968 northeast of the mouth during synoptic studies (Goldman, Moshiri, and Amezaga 1972). Correlations of productivity with plume density, suspended sediment, DIC, and heterotrophic activity are good except for 29 March (Table 27). However, there are usually one or two stations in each study that exhibit markedly different primary productivity than expected based on plume density and heterotrophic activity values. Discrepancies in primary productivity are probably due, in part, to physiological factors rather than physical conditions. For example, placement of phytoplankton from a turbid water environment in clear water for incubation could cause anomalous results since light values could be higher.

Productivity was greater in March than April at all but two stations. The plume was highly developed and evidently contained rain runoff from the 26 March storm. It probably carried a high nutrient load in melting snows from lower altitude urban areas. The plume was well developed in April, but higher productivity was limited to the immediate river mouth area and a few areas to the northeast and east. Increased productivity occurred at all stations on 7 June. Values were highest at the river mouth and decreased sharply to the west and less sharply eastward; no major discrepancies in primary productivity compared to plume density and heterotrophic activity occurred. The morning sampling on 20 June resulted in lower values of phytoplankton growth rate, but the pattern was less distinct (note lower confidence levels for productivity vs. sediment, DIC, and heterotrophic activity in Table 27). The afternoon sampling resulted in high correlations between plume density, heterotrophic activity, and primary productivity. The morning and afternoon studies confirmed that productivity as well as other indicative values were illustrative of the plume's eastward shift during the afternoon. This discovery is to some degree tempered by the fact that the incubation procedure differed (see Methods).

Phytoplankton - Except for studies on 20 June, correlations of the number of cells per unit volume or biomass with other parameters were almost non-existent. It is unclear why good correlations exist only on 20 June. The lack of consistent correlations emphasizes the differences between measures of standing crop and measures of metabolic activity or environmental conditions. Since biomass measurement required phytoplankton identification, it was possible to observe trends of various species by station location and throughout the period of study. The trends were not tested by simple correlations, but the observations follow.

The largest biomass level for any of the studies was recorded on 29 March.

There were distinct differences in phytoplankton community composition between near and off-shore stations for that plume. The phytoplankton community of each station was dominated by three or four diatoms which were the major biomass contributors except in close proximity to the river mouth. *Cyclotella bodanica*, *Melosira crenulata*, and *Synedra radians* were usually the most abundant species. *Synedra radians* provided the single largest biomass component. Other diatoms such as *Asterionella formosa*, *Fragilaria crotonensis*, and the chrysophycean *Dinobryon sertularia* were abundant locally and together with *Cryptomonas reflexa*, *Euglena* sp., and some flagellates were responsible for most differences in phytoplankton composition detected near the river mouth. The greatest measured cell concentration and biomass occurred just to the east of the inflow where the highest primary productivity was found (Fig. 38).

Early April sampling revealed a similar phytoplankton composition with *Synedra*, *Cyclotella*, and *Melosira* dominating. *Asterionella* appeared again close to the river mouth, but *Dinobryon*, which had also been an indicator of plume location, was much less prevalent. *Cryptomonas*, *Euglena*, and the flagellates were not present. *Melosira* was more abundant in the plume than at locations to the west. Samples to the northeast and around the river mouth contained the largest biomass. Total values were lower than those in March.

The 7 June sampling was marked by a definite decrease in dominance of the major diatoms and by important but isolated appearances of the green algae *Staurastrum paradoxum* and some other diatoms, such as several species of both *Achnanthes* and *Epithemia*. There was a significant resurgence of *Dinobryon* and a very large increase in *Peridinium* sp. and flagellates at most sampling locations. *Asterionella formosa* was present in samples near the river mouth, but also occurred in many samples within the plume influence to the east and north. Consistent with the higher primary productivity, there was a larger number of cells, but with lower biomass than in April; the highest values of both occurred east of the river mouth.

The two samplings on 20 June revealed a continuing trend toward greater community diversity along with subsidence of previously abundant forms and Staurastrum. Dinobryon became much more abundant and so did another chrysophycean Kephyrion ovum. Flagellates were present in a fan-shaped pattern north of the river mouth, but did not appear to the east or west along the shoreline. In contrast to Asterionella, which again was locally abundant in the plume, Dinobryon showed a general increase in numbers with increasing distance away from the plume. Peridinium was abundant at almost all stations. Many diatom species were present at the river mouth, both in the morning and afternoon, possibly indicative of the dynamic nature of the sampling area and mixing of water and phytoplankton from both lentic and lotic environments. Cell numbers and biomass increased in the afternoon and there was a distinct shift of the phytoplankton population east of the river mouth during the day, concurrent with visible evidence of plume movement. Total cell numbers were lower than on earlier dates, but biomass decreased only slightly.

Discussion

Sediment plumes of the Upper Truckee River can be mapped for both position and density a considerable distance into Lake Tahoe by aerial photography and simultaneous field collections of water truth data. Several chemical and physical parameters correlate with mapped plume positions and densities. Most importantly, biological measurements of bacterial and phytoplankton activity clearly show the influence of the plume. These measures of biological activity are particularly useful in assessing eutrophication processes. Bacterial activity is strongly related to increasing plume density as the Upper Truckee River mouth is approached. It is suggested that suspended detrital material, issuing from the river mouth, stimulates bacterial growth, because it simultaneously provides attachment surfaces for bacterial adhesion and a concentrated nutrient source. Bioassay experiments with nutrient-stripped, sterile silt added to mid-lake water provided attachment surfaces and showed striking amounts of stimulation over mid-lake water without silt (Paerl and Goldman 1972b). These experiments were conducted with similar final concentrations of organic and inorganic nutrients, thus proving that surface area is of prime importance to promotion of bacterial growth. In addition to surface area, the high nutritive content of silt in the sampling area (nitrate, phosphate, organic carbon) further boosts bacterial growth. Additional evidence of bacterial attachment comes from micro-autoradiographic experiments showing bacteria actively assimilating heterotrophic substrates while attached to silt (Paerl and Goldman 1972b). It would appear that attached bacteria utilize nutrients from silt as well as solution. An alternate explanation of the heterotrophic activity-plume density relationship is that the bacteria attached to silt particles derive from the original soil. Hence, good correlation between the two parameters would be caused by the fact that soil bacteria are always attached to the silt. However, the above experiment with sterile silt showed stimulation of mid-lake bacteria as opposed to soil bacteria. Secondly, the bacteria continue to survive and multiply in the lake environment so that any effect on the lake is identical irregardless of their origin. Through mineralization, nutrients are eventually available for later uptake by phytoplankton. In addition, the hundred-fold change of heterotrophic activity caused by sediment plumes raises the possibility that a minor biomass component, bacteria, may have major effects on eutrophicating processes, namely breaking down organic sediment to release nutrients for algal growth (Paerl and Leonard unpublished).

The relationship between phytoplankton productivity and mapped plume density is less dramatic, but the correlation varies between 99% and 99.9% confidence levels except for 29 March. Lack of correlation on that date is probably due to an hour's time lag between photographic observation and beginning aquatic sampling; field notes indicate a plume shift sufficient to change the character of the water mass at a number of stations. Subsequent studies commenced aerial and aquatic efforts simultaneously, albeit for other reasons. Phytoplankton utilize dissolved nutrients and not those attached to silt as do heterotrophs. In view of spotty correlations between plume density and dissolved nutrients, which may be caused by biological utilization (see below), it is not surprising that primary productivity displays lower correlation than heterotrophic activity with plume density.

Nutrients under plume influence owe their changes, in part, to biological processes which utilize them. Lake Tahoe contains very low concentrations of nutrients and primary productivity has been proven to be nitrogen and iron limited (Goldman and Armstrong 1969, Goldman 1964). Biological utilization may well have contributed to the spotty correlation with plume density. Changing concentrations of these nutrients during 20 June may be linked to both increased inflow of nutrients from the river as well as biological utilization.

Changes in phytoplankton diversity, cell numbers, and biomass were indicative of the Upper Truckee River sediment plume. But while they signaled the changing seasonal conditions in the lake, the relationship of these phytoplankton characteristics to plume density is unclear. Only during 20 June was there a strong correlation (Table 27) between plume density units and total cell numbers or biomass. Unless inflow brings in new species and/or greater numbers of phytoplankton, the change in plume configuration is too rapid to produce a good correlation between phytoplankton and plume density. However, it is clear from the data that certain algal species are quite indicative of plume presence.

Several types are either excluded from the area adjacent to the river mouth or are more abundant than in other areas. It is apparent that phytoplankton community changes, although useful indicators, taken alone cannot define the effects that a tributary has on Lake Tahoe.

Good correlations between photographic and aquatic data imply that it is reasonable to assign similar values to various water parameters in unsampled areas. The values can be assigned to mapped units with a certainty corresponding to the degree of correlation (Table 27). High heterotrophic activity represents plume units of high density and the activity of even the least dense units will be higher than clear water. The data also suggests that the Upper Truckee River sediment plume probably causes higher than normal levels of primary productivity to extend over much of the southeastern corner of the lake. Photographs show that the sediment plume grows from early spring to reach its maximum size during peak river discharge. The data indicate that primary productivity followed a similar development and that the Upper Truckee River plume has become a permanent influence on algal growth in the lake.

Spatial and temporal association of high biological activity with the Upper Truckee River sediment plume is circumstantial evidence that the sediment plume is the causative agent, but additional evidence must be added to demonstrate a causal relationship. The strong relation between plume densities, suspended sediment, and heterotrophic activity coupled with the evidence for bacterial attachment to and nutrition by sediment particles is strong evidence for stimulation caused by sediment particles. The link between plume densities and primary productivity, while less dramatic, is important because it measures actual algal growth rate in the lake. Good correlations exist between primary productivity and plume density; plume density is correlated with nutrients for the first two and last studies, but biological utilization may have destroyed the correlation for the other two as well as that between primary productivity and nutrients. Previous work (Goldman and Armstrong 1969) showed high nutrient levels in Upper Truckee River water (such as were consistently measured at the mouth station in this work) increased primary productivity in the lake's water. Taken together, the two lines of evidence indicate that the nutrients associated with the sediment plume are the causative agents of increased primary productivity. Thus, both measures of biological productivity indicate that the sediment plume is the causative agent of increased production.

Conclusions

Aerial photographs and simultaneous on-site water samples in Lake Tahoe can be used to document temporal and spatial influences of the Upper Truckee River sediment plume on a yearly or daily basis. DIC and heterotrophic activity are highly correlated with photographic evidence and appear to be especially promising methods of water mass delineation. Nutrients, sediment load, light penetration, temperature, phytoplankton community changes, and primary productivity can also be useful when samples are numerous enough for correlation with photographic records.

Relationships between the sediment plume and both primary productivity and bacterial activity implicate sediment particles and associated nutrients with more rapid nutrient utilization and growth by bacteria and phytoplankton. Coupled with these findings, the sediment load in the Upper Truckee River from man-made disturbances in its watershed is increasing. It appears that land disturbance is contributing further to accelerated eutrophication of Lake Tahoe.

Methods described here should be applicable to other situations where tributary inflows to a river or lake are visibly different in clarity. Collection of similar baseline limnological information is a continuing necessity for proper interpretation of tributary influences evidenced by photographic data.

LAND DISPOSAL OF SEWAGE EFFLUENT

(This sub-section is to be published in Ecology by Michael A. Perkins, Charles R. Goldman, Robert L. Leonard, Division of Environmental Studies and Institute of Ecology, University of California, Davis).

Introduction

Heavenly Valley Creek is a small subalpine creek located in the Trout Creek drainage system at the southern end of the Lake Tahoe basin (Fig. 44). This creek was sampled initially in April 1970, during a stream survey designed to locate the source of high ultraviolet absorbance in the waters emanating from the south shore region of the basin as reported by Goldman and Armstrong (1969).

Samples from Heavenly Valley Creek had much higher UV absorbance readings than did those from other streams in the region sampled at the same time. Chemical analysis of the samples indicated a nitrate-nitrogen (NO_3-N) concentration of 1.08 $mg \cdot l^{-1}$ for Heavenly Valley Creek. This value was unusually high for streams of the Tahoe basin, where NO_3-N values rarely exceed the microgram per liter level (Fig. 45).

The high NO_3-N concentration and associated UV absorbance of Heavenly Valley Creek warranted further investigation into land use practices within the subdrainage. A conference with the United States Forest Service revealed that the area to the immediate south of the creek was one of two areas in the south shore region that had received surface spraying of sewage effluent from the South Tahoe Public Utilities District (STPUD) plant. Area 1, located to the south of Heavenly Valley

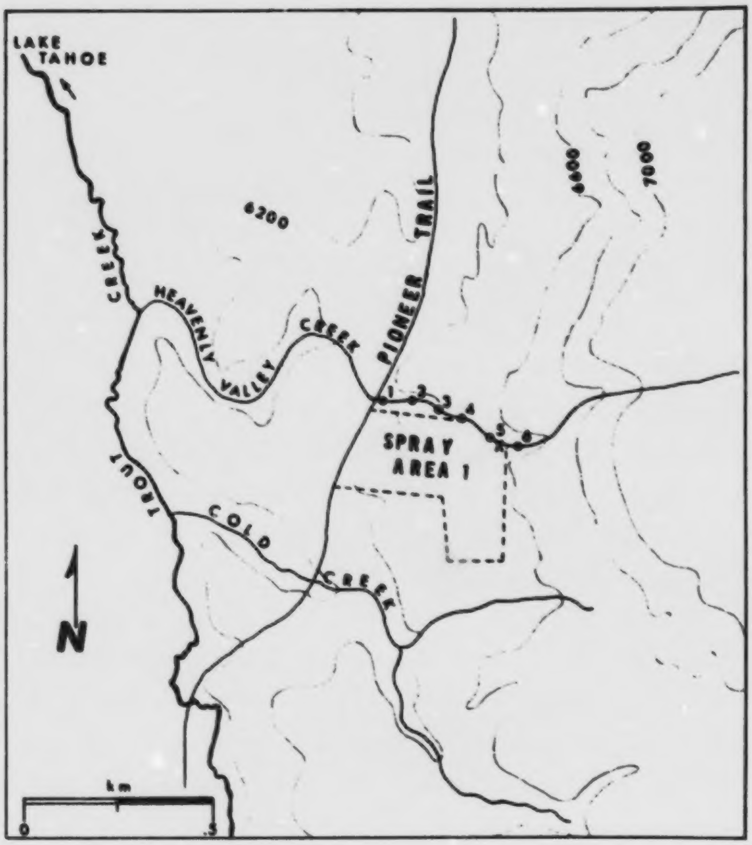

LAKE TAHOE
TROUT CREEK
HEAVENLY VALLEY CREEK
PIONEER TRAIL
6200
6600
7000
1
2
3
4
5
6
X
SPRAY AREA 1
COLD CREEK
N
km
0
.5

Figure 44. Heavenly Valley Creek area indicating the site receiving effluent spray. The numbers (1-6) represent sample stations along the creek. The location of the spring draining from the spray area is designated by X.

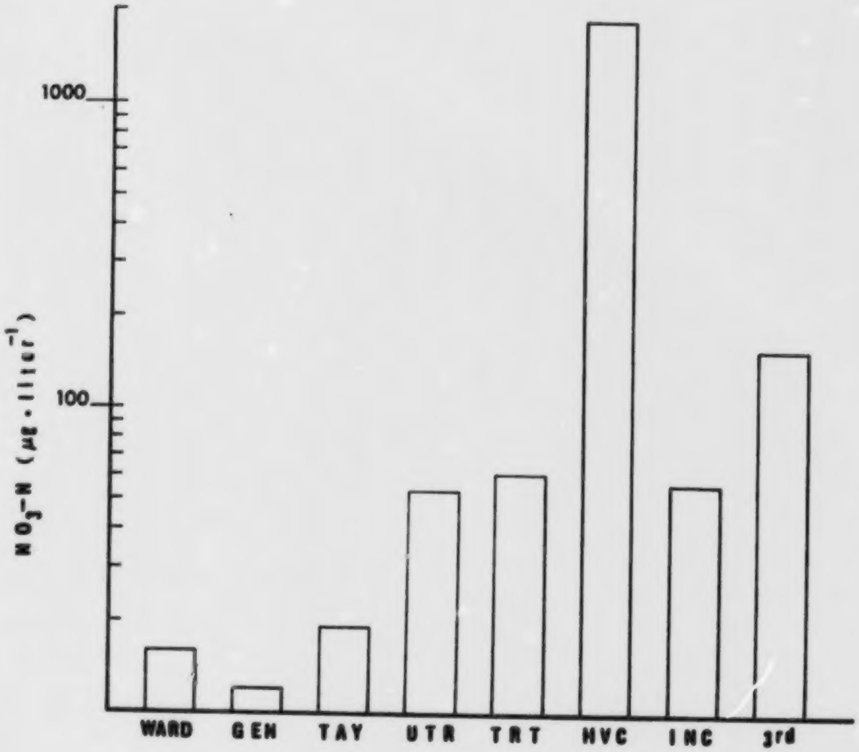


Figure 45. Nitrate-nitrogen concentrations for eight creeks within the Tahoe basin. Values are means of 13 samples collected between January and June 1971.

Creek, consisted of approximately 40.5 hectares (100 acres) which were sprayed with secondary effluent from 1960 to 1965 (Fig. 44). Area 2 (outside the study area shown in Fig. 44), located between Trout Creek and the Upper Truckee River, consisted of approximately 58.3 hectares (144 acres) which were sprayed from 1966 to 1968. The effluent was derived entirely from residential and commercial service, including gambling casinos in the Nevada Stateline area. No significant industrial effluents or other sources of unusual toxic substances were involved. Although Area 2 does not influence Heavenly Valley Creek, its drainage does enter the Upper Truckee River and Lake Tahoe. After April 1968 the facilities for exporting tertiary effluent out of the basin to Indian Creek Reservoir, 45 km south, were completed (Culp and Moyer 1969).

A striking feature of the study site was the absence of large stands of coniferous trees within the area which had received effluent spray. Prior to effluent spraying, this area contained a moderately dense stand of Jeffrey pine (Pinus jeffreyi) with sparse shrub cover. Most of the pines died during the period of effluent treatment. The pines were most likely killed by prolonged soil saturation. Normal summer soil moisture conditions in the Tahoe basin range from field capacity in late June, just after snowmelt, to extremely dry by September and often through November before heavy snowfall. Boron in the soil may also have reached toxic levels (2 $mg \cdot l^{-1}$ was found in the soil after prolonged spraying, Paul Zinke personal communication). After cessation of spraying, the dead trees were cleared from the site and an attempt was made to revegetate the area (U.S. Forest Service personal communication).

This report is an evaluation of one aspect of the long term effects of spraying treated effluent directly upon the forest floor in the Tahoe basin. The secondary effluent, as it percolated through the soil profile, was partially stripped of its rich nutrient load through biological uptake and adsorption onto soil particles. A residual nutrient load apparently remained within the soil profile to be leached in future years. Five years after cessation of spraying onto Area 1, the release of high levels of nutrients, particularly NO_3-N, into Heavenly Valley Creek was still observed. These nutrients are eventually carried into Lake Tahoe.

Methods

Six stations were selected at approximately 200 m intervals along Heavenly Valley Creek in order to locate and further investigate the source of the NO_3-N and the substance responsible for the high UV absorbance. Water samples collected at these sites in 2-liter, acid-rinsed, polyethylene containers were transported to the Davis laboratory for analysis. If immediate analysis was not practical, the samples were frozen and analyzed at a later date.

Nitrate-nitrogen was determined by the cadmium-reduction method of Strickland and Parsons (1968). Phosphate-phosphorus, as total acid-hydrolyzed phosphate, was determined by a modification of the single-solution method of Murphy and Riley (1962), using butyl acetate extraction for low levels of phosphate. Na^+, Mg^{++}, and Ca^{++} were determined by atomic absorption spectrophotometry. Ultraviolet absorbance was measured on filtered samples (Whatman GFC) at 200 nm in 1 cm quartz cells in a Beckman DBG spectrophotometer.

Ground-water extractors were distributed within the study area to test for nutrient differences between sprayed and unsprayed sites. An extractor consisted of a length of PVC tubing (6.5 cm diameter) fitted with a porous ceramic cup at one end and a rubber stopper at the other (Soil Moisture Equipment Co., Santa Barbara, Calif.). The extractors were placed in the ground to a depth of 120 cm and were then evacuated through a tube in the rubber stopper. Ground water samples, drawn through the porous cups from the soil, were collected from the extractors every two weeks and analyzed as described above. The area to the immediate north of the creek, opposite Station 5, was chosen for the unsprayed sample location since it was completely outside the influence of the sewage spray (Fig. 44). The soil on either side of the creek consisted primarily of coarse-textured, decomposed granite.

Lake water enrichment bioassays were set up to test the effect of Heavenly Valley Creek water on photosynthetic carbon fixation. The method used was a modification of that described by Goldman and Armstrong (1969). ^{14}C-carbonate (20 $\mu c \cdot ml^{-1}$) was added to Lake Tahoe water taken from a depth of 15-20 m. The water was then distributed into 500-ml, screw-cap, culture flasks. Stream water from various stations along the creek was introduced into the culture flasks to make 0.1, 1.0, and 10.0% (v/v) additions. The flasks were incubated at 18°C with a 14-hour light period. Fifty-milliliter subsamples were taken at 24-hour intervals over a five-day period and filtered through 0.45 ± 0.02 μm HA Millipore® filters at low vacuum (<10 psi). The filters were air dried and then placed on planchets for counting of radioactivity in a Geiger-Mueller, ultra-thin window, gas flow system. All controls (untreated lake water) and additions for each culture period were run in triplicate. Replicate samples, expressed as counts-per-minute, agreed within 10% for all culture periods.

To supplement the information gained from the stream water bioassays, soil samples were collected from depths down to 45 cm in both the sprayed and unsprayed areas. These samples were passed through a 2 mm mesh sieve and then placed in a 4 cm diameter plexiglass column for leaching with quartz-distilled water at a water:soil ratio of 5:1. The soil-water extract obtained was added to Lake Tahoe water to make 0.1, 1.0, and 10.0% (v/v) additions. Culture conditions were the same as those outlined for the stream water additions.

Results and Discussion

Stream water samples taken along Heavenly Valley Creek in May 1970 revealed significant differences in both NO_3-N and UV absorbance between Stations 5 and 6 (Fig. 46). More intensive sampling indicated that the break occurred abruptly at a point in the creek fed by a small spring draining from the south slope. The initial samples from this spring had a NO_3-N concentration of 12.4 $mg \cdot l^{-1}$ and a UV absorbance which read off-scale. Samples taken 5 m upstream and downstream from the spring had respective NO_3-N concentrations of 0.02 and 0.35 $mg \cdot l^{-1}$ and UV absorbance values of 0.152 and 0.452. It was evident that the spring was a major source of both the high NO_3-N concentration and the high UV absorbance values in the creek.

The spring lies at the highest point along the creek receiving immediate drainage from the sprayed area. Thus, it seemed likely that the exceptionally high NO_3-N concentration and UV absorbance of both the spring and the creek could be attributed to the past treatment of the adjacent area with sewage effluent.

A weir was placed across the spring and flow rate and nutrient output were measured twice a month from February through June 1971. The flow rate remained fairly constant at about 0.045 $m^3 \cdot min^{-1}$ (0.026 cfs) until a thaw in April, at which time the rate increased to 0.076 $m^3 \cdot min^{-1}$ (0.044 cfs), a level maintained throughout the remainder of the study period. NO_3-N output averaged 854 $g \cdot day^{-1}$ during the period of low flow and 1818 $g \cdot day^{-1}$ during the period of increased flow. Overall, NO_3-N output ranged from 750 to 2198 $g \cdot day^{-1}$, with a mean value of 1336 $g \cdot day^{-1}$.

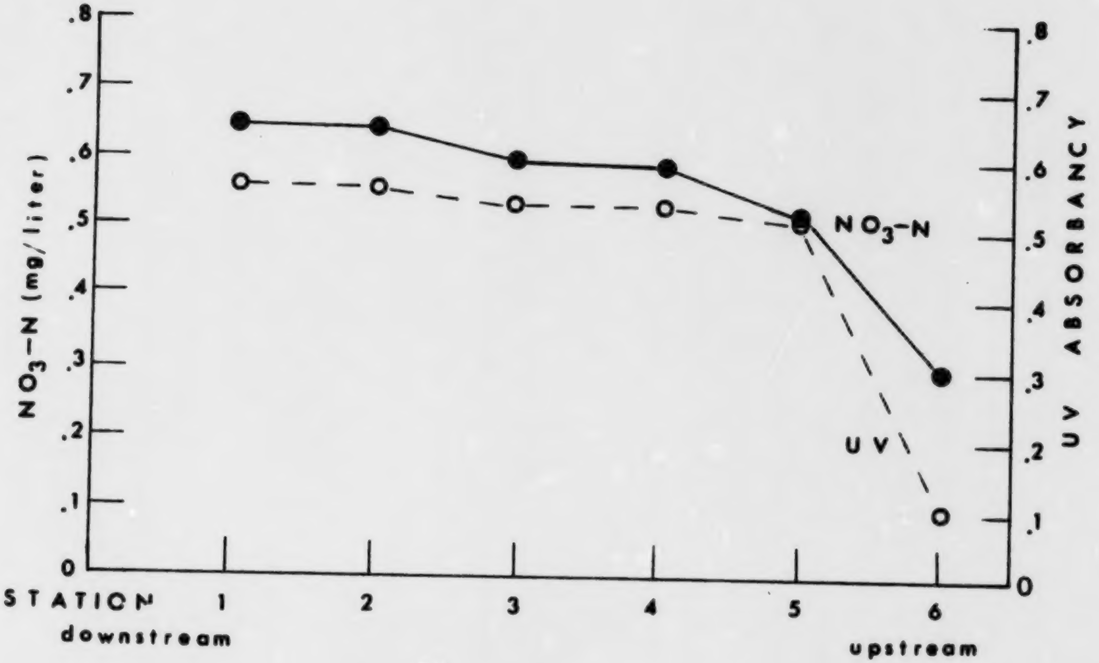


Figure 46. Nitrate-nitrogen and UV absorbance along Heavenly Valley Creek in May 1970. Note the sharp drop in nitrate and UV absorbance between Stations 5 and 6.

A downstream station, an upstream station, and the spring were sampled periodically from July 1970 through June 1971 (Fig. 47). Nitrate concentrations at the downstream station ranged from 0.25 to 3.75 mg NO_3-$N \cdot l^{-1}$ with a mean value of 1.25 $mg \cdot l^{-1}$ (SD = 0.98). The concentration of NO_3-N was always much lower at the upstream station with a mean value of 0.038 $mg \cdot l^{-1}$ (range = 0.007-0.082 $mg \cdot l^{-1}$, SD = 0.007). On the average, there was an increase of 1.212 $mg \cdot l^{-1}$ from the upper to the lower station. The nitrate concentration of the spring was much greater and fluctuated widely. The mean value was 11.84 $mg \cdot l^{-1}$ over a range of 0.825 to 23.60 $mg \cdot l^{-1}$.

In order to calculate total nitrate loading of Heavenly Valley Creek from the effluent spray site, including the spring and direct entry into the stream channel below the spring, monthly water discharge from Heavenly Valley Creek was estimated from Trout Creek records of the U.S. Geological Survey taken above and below the confluence of the two streams. The total nitrate load carried by Heavenly Valley Creek for the period July 1970 to June 1971 was estimated to be about 6000 kg (nitrate concentration data from Fig. 45). This amount of nitrate is well over 20% of the average total nitrate carried into Lake Tahoe annually by surface runoff (Goldman 1974); it is nearly 60 times more nitrate-nitrogen than was carried by Ward Creek in water-year 1972-73 (Leonard and Coats 1974). (Values were adjusted for differences in total water discharge between the two watersheds and water-years). Annual average nitrate concentrations in Lake Tahoe as a whole are still low (13 $\mu g \cdot l^{-1}$ in 1972-1973, Paerl et al. 1974), but may have increased in the past 10-20 years (Goldman and Armstrong 1969). In addition, tributary enrichment with nutrients has caused highly visible algal blooms in localized areas at the southern end of the lake (Goldman et al. 1974).

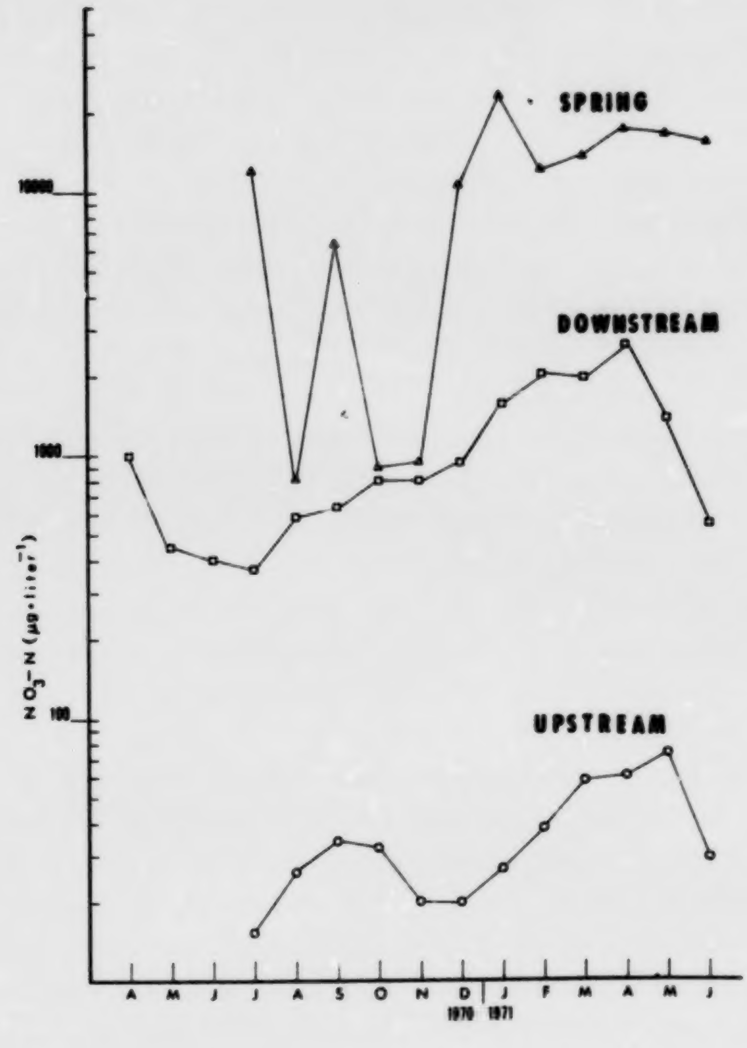


Figure 47. Seasonal nitrate-nitrogen concentration at the upstream, spring, and downstream stations of Heavenly Valley Creek from April 1970 to June 1971.

Phosphate levels were fairly low throughout the sampling period. There appeared to be no discernible pattern among the values at the three stations sampled indicating that the drainage from the spray area was not significantly affecting phosphate concentration in the creek. The mean values were: upstream, 0.019 $mg \cdot l^{-1}$; spring, 0.034 $mg \cdot l^{-1}$; and downstream, 0.023 $mg \cdot l^{-1}$.

Cation analyses initiated in January 1971 revealed concentration patterns similar to that of NO_3-N which increased gradually through the summer, fall, and winter and then dropped sharply in the spring. Na^+, Mg^{++}, and Ca^{++} all showed a gradual increase through the winter months followed by a decreased concentration in April, May, and June, reflecting the dilution effect of spring snowmelt. The mean values at the downstream station were: Na^+, 2.34 $mg \cdot l^{-1}$ (range = 1.30-3.02 $mg \cdot l^{-1}$); Mg^{++}, 1.14 $mg \cdot l^{-1}$ (range = 0.26-1.43 $mg \cdot l^{-1}$); and Ca^{++}, 3.01 $mg \cdot l^{-1}$ (range = 1.28-3.90 $mg \cdot l^{-1}$).

Due to sampling difficulties, data on concentration of groundwater nutrients are sparse. The mean NO_3-N concentration for 13 samples from the sprayed area was 3.99 $mg \cdot l^{-1}$ (range = 0.65-7.8 $mg \cdot l^{-1}$, SD = 2.33). Six samples taken from the unsprayed area had a mean concentration of 0.49 $mg \cdot l^{-1}$ (range = 0.04-1.00 $mg \cdot l^{-1}$, SD = 0.42). The mean concentration was approximately eight times greater in samples from the sprayed area. Concentration of Na^+ in the samples from the sprayed area averaged 451% higher than in samples from the unsprayed area, the mean values being 14.93 and 3.31 $mg \cdot l^{-1}$, respectively. There were no differences in the other elements included in the groundwater analyses which might be attributed to the sewage effluent.

At no time during the investigation of Heavenly Valley Creek was conspicuous periphyton growth noticed, a fairly common feature of many streams in the Tahoe basin. This lack of abundant periphyton growth seemed inconsistent with the high nutrient levels in the creek, particularly in its downstream reaches where suitable sites for algal attachment and other favorable environmental conditions existed. The possibility of algal inhibition by substances being released into the creek via subsurface drainage from the sprayed area was suspected. The C-14 bioassays of the stream water and soil extract additions to Lake Tahoe water were set up to test this possibility.

The data for the stream water additions compared to untreated controls appeared to support the hypothesis that high concentrations of substances present in Heavenly Valley Creek were inhibiting algal growth in the stream itself. The various additions of downstream and spring water were either slightly inhibitory, slightly stimulatory, or had no apparent effect upon photosynthetic carbon-fixation by Lake Tahoe phytoplankton. The spring and downstream stations showed slight stimulation only for the 0.1% addition while the 1.0 and 10.0% additions gave no effect or slight inhibition. The addition of upstream water gave the expected stimulatory response for the 0.1 and 10% additions (Fig. 48). A one-way analysis of variance of the stream water additions indicated that only the 10% upstream addition differed significantly from the control and other additions (95% confidence level) showing a 22% increase over the control.

Goldman and Carter (1965) and Goldman and Armstrong (1969) have shown that algal photosynthesis in Lake Tahoe is relatively sensitive to rather minute additions of inorganic nutrients, especially NO_3-N. Considering the amount of nutrients being added through the addition of stream water, the lack of a stimulatory response was surprising. The upstream additions had the least amount of added NO_3-N (0.1% = 0.015 mg, 1.0% = 0.15 mg, 10% = 1.5 mg) and gave the greatest stimulatory response. The spring and downstream additions contained considerably more NO_3-N and yet showed a stimulatory response only for the 0.1% additions

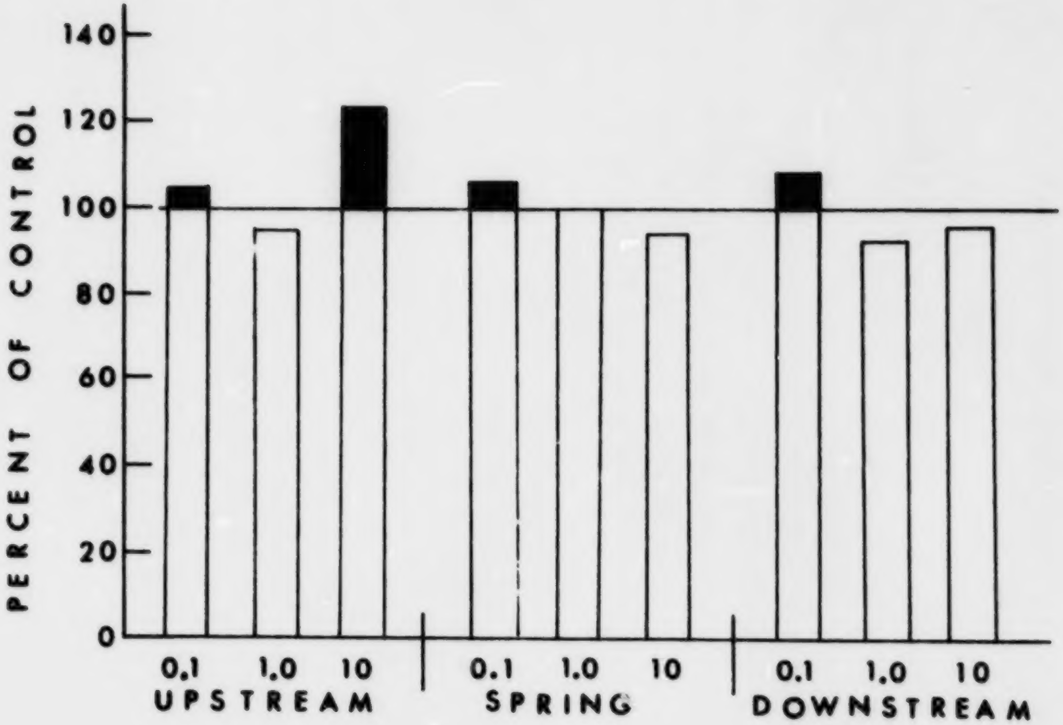


Figure 48. Bioassay of Heavenly Valley Creek water additions to Lake Tahoe water. Shaded areas represent percent increase over an untreated lake water control.

(Fig. 48). It is evident that some substance present in the spring and downstream water, possibly the nitrate, is inhibitory to algal growth and that its effect is negated and even reversed through dilution. Nitrate is usually stimulatory at relatively low concentrations ($<50\ \mu g \cdot l^{-1}$), but can be inhibitory at higher concentrations in lake water algal cultures.

The soil extract additions from the sprayed area showed only slight stimulation for the 1.0 and 10% additions from the upper horizon of the soil profile (0-15 cm), the increase relative to the control being 17 and 5%, respectively (Fig. 49). All additions from the lowest horizon sampled (30-45 cm) resulted in significant inhibition of photosynthesis as compared to the control, the lowest being the 10% addition which gave a value 26% less than the control (Fig. 49). A one-way analysis of variance comparing the two depths sampled indicated that the 1.0 and 10% additions from the lower depth (30-45 cm) resulted in significant inhibition of photosynthesis relative to equal additions from the upper horizon (0-15 cm).

After 96 hours of incubation, all additions of soil extract from the unsprayed area had resulted in significant increases in photosynthesis relative to that of the control (Fig. 49). All additions from the unsprayed area were significantly more stimulating to photosynthesis than were equivalent additions from the sprayed area.

A one-way analysis of variance comparing the two depths sampled within the unsprayed area indicated that for equal additions only the 10% addition varied significantly, the extract from the lower depth (30-45 cm) being 38% more stimulating to algal photosynthesis.

These results lend further support to our hypothesis that substances present in the subsurface drainage from the sprayed area are inhibitory

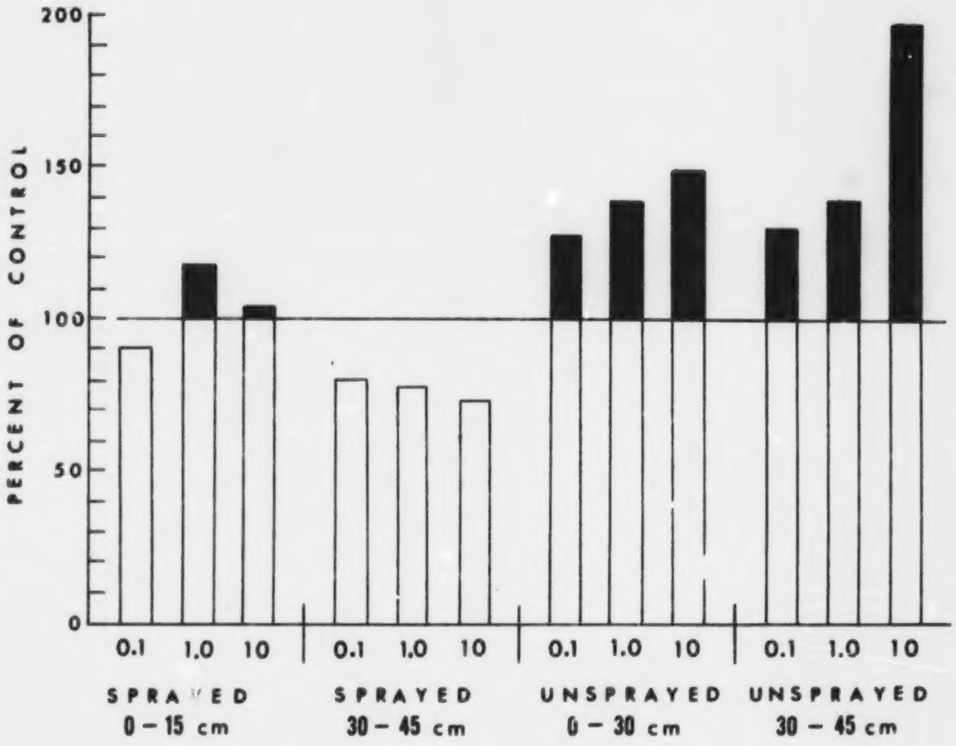


Figure 49. Bioassay of Heavenly Valley soil extract additions to Lake Tahoe water. Shaded areas represent percent increase over the control.

to algal growth at the concentrations present in Heavenly Valley Creek. These substances are probably related to the past treatment of the area with sewage effluent.

Conclusion

The combined results of the chemical analyses and bioassay experiments indicate that unique nutrient characteristics of the lower reaches of Heavenly Valley Creek are related to the history of sewage effluent spraying in Area 1 (Fig. 44). Exceptionally high concentrations of NO_3-N were released from the sprayed area into the stream. Cooper (1969) has commented on the nutrient regulating effect of forest vegetation by uptake and storage as well as by influencing the flow of water through the soil profile. Bormann et al. (1968) have demonstrated the increased nutrient output due to removal of forest vegetation and the importance of vegetation in maintaining nutrient cycling within the ecosystem. The results presented in this report are indicative of a similar type of nutrient release which when coupled with the accumulation of nutrients contained in sewage effluent can create a long term potential for eutrophication of the receiving body of water.

Phytoplankton growth in Lake Tahoe has been shown to be most limited by nitrate (Goldman and Carter 1965, Goldman and Armstrong 1969, Goldman 1972). Goldman and Armstrong (1969) have also shown close correlation between primary productivity and UV absorbance in lake waters off the South Shore. They suggested that this UV absorbance may be due to nitrate and/or dissolved organic matter (DOM), present in the water. Although the data did not reveal a consistently strong, positive correlation between nitrate and UV absorbance in the present study, there was no doubt that the high UV readings were traceable to drainage from the sprayed area. The UV absorbance noted by Goldman and Armstrong (1969) and its correlation with primary productivity were in fact indicators of the enrichment of south Lake Tahoe water by drainage from the two sprayed areas within the Trout Creek-Upper Truckee River watersheds.

Because of the sensitivity of the coniferous soil-vegetation system to unseasonal flooding and possibly to toxic substances in the effluent and the sensitivity of the aquatic system to nutrient additions, large-scale land disposal of secondary sewage effluent is inappropriate in the Tahoe basin.

THE RESPONSE OF NATURALLY OCCURRING PHYTOPLANKTON POPULATIONS TO NTA IN LAKE TAHOE, CASTLE LAKE, AND CLEAR LAKE, CALIFORNIA

Introduction

The mounting concern about the eutrophication of surface waters has directed attention toward the high phosphate content of conventional detergents, since phosphorus has long been considered a major limiting factor in aquatic environments. High phosphate concentrations are often found in very eutrophic waters. Limiting factor work at the University of California, Davis has identified a number of different limiting factors in Alaska, New Zealand, and California lakes (Goldman 1964). Molybdenum, for example, was found to be a limiting factor in Castle Lake, California in combination with potassium and sulfur (Goldman 1960) Clear Lake, the largest lake entirely within the boundaries of California, is characterized by extremely high phosphate levels with nitrogen the most limiting of the spectrum of stimulatory chemicals (Goldman and Wetzel 1963). Lake Tahoe, long renowned for its remarkable clarity and low nutrient content, is primarily limited by iron (Goldman 1964) and nitrogen (Goldman and Armstrong 1969).

Because of the extensive limnological research that has been done with these three lakes, they were selected for bioassay experiments with NTA which has been proposed as a phosphate substitute in the detergent industry. During the summer and fall of 1970, culture experiments with natural lake populations were conducted to determine the influence of NTA on algal growth. NTA in various forms for these experiments was supplied by the E.P.A. Pacific Northwest Environmental Research Laboratory. Natural populations of phytoplankton were used exclusively in these experiments without concentration. Both laboratory and in situ culturing were employed.

Although NTA was banned in detergents for other reasons, it appears likely that its eutrophicating potential in some California lakes might have been just as great if not greater than the phosphate it was to replace.

Methods

The carbon-14 bioassay techniques developed by Goldman (1963) were used in this study. Solutions of $Na_2{}^{14}CO_3$ of known activity were carefully premixed in the total culture medium prior to the addition of the NTA solutions being tested. The following amounts of ^{14}C were added to each of the cultures:

Lake Tahoe	50.0 $\mu c \cdot l^{-1}$	(50 subsample filtered daily)
Castle Lake	8.0 $\mu c \cdot l^{-1}$	(50 ml subsample filtered daily)
Clear Lake	5.4 $\mu c \cdot l^{-1}$	(25 ml subsample filtered daily)

Carefully washed and autoclaved 500-ml Pyrex® culture flasks were used in all experiments. Whether incubated in situ or in the laboratory, well-mixed subsamples of each culture were filtered daily through HA Millipore® discs of 30 mm diameter. The experiments lasted from 4 to 7 days. The radioactivity of the organisms retained on these filters was measured with an ultra-thin window, automatic, gas-flow Geiger-Müller counter.

Nitrate determinations were made with the cadmium reduction method of Strickland and Parsons (1968). Phosphorus was determined colorimetrically as the blue phosphomolybdate complex, based on a method that closely paralleled that of Murphy and Riley (1962). Total iron was measured after conversion to the ferrous state with hydrochloric acid and hydroxylamine. The red iron (II)-bathophenanthroline complex extracted into isopentyl alcohol was measured colorimetrically. Dissolved inorganic carbon concentrations were determined by the infrared analysis method of Armstrong, Goldman, and Fujita (1971).

All experiments used dilutions from 5.00 mg $Na_3NTA \cdot H_2O \cdot l^{-1}$ stock solutions (equivalent to 3.44 mg $NTA \cdot l^{-1}$). Series #29500 - 29503 and #39500 - 39503 sewage effluents from the Corvallis laboratory pilot plant were used in these experiments. Chemical analyses of these effluents provided by the E.P.A. are given in Tables 28 and 29.

Exact details of the experimental procedures were sometimes modified for the different tests. Therefore, a more detailed description of each experiment identified by number is included below.

Lake Tahoe studies included one *in situ* and one laboratory incubation experiment.

Lake Tahoe NTA Culture (LTC-IV-70), 27-31 July 1970 - Water was collected 27 July at a depth of 20 m from the index station. Chemical analyses of water collected at the same location on 24 July for total phosphorus (3.8 µg $P \cdot l^{-1}$), nitrate-nitrogen (2.1 µg $N \cdot l^{-1}$), and inorganic carbon (916 mg $C \cdot l^{-1}$) were performed. After spiking with NTA and sewage effluent solutions, the samples were incubated in the laboratory at Lake Tahoe. Included in this study were 0.01% - 1.0% dilutions of the NTA stock solution and series #29500 - 29503 sewage

TABLE 28. CHEMICAL ANALYSES OF SERIES 29500 - 29503 SEWAGE EFFLUENTS

SUBSTANCE	#29500	#29501	#29502	#29503
TOTAL C (mg/1)	21	24	22	?
TOTAL ORGANIC C (mg/1)	2	3	2	2
TOTAL INORGANIC C (mg/1)	19	21	20	?
AMMONIA - N (mg/1)	<1	<1	< 1	<1
NITRITE - N (mg/1)	<0.1	<0.1	<0.1	<0.1
NITRATE - N (mg/1)	23.1	23.1	24	24.2
KJELDAHL - N (mg/1)	3	0.3	0.3	0.1
ORTHOPHOSPHATE - P (mg/1)	7.56	7.20	0.84	0.60
pH	7.3	7.3	7.0	7.3
TOTAL ALKALINITY (mg/1)	59	64	82	82
BICARBONATE ALKALINITY (mg/1)	59	64	82	82
DISSOLVED FE (μg/1)	260	160	< 100	< 100
NTA (mg/1)	<0.1	<0.1	<0.1	<0.1

TABLE 29. CHEMICAL ANALYSES OF SERIES 39500 - 39503 SEWAGE EFFLUENTS

SUBSTANCE	#39500 SECONDARY EFFLUENT + NTA	#39501 TERTIARY EFFLUENT + NTA	#39502 SECONDARY EFFLUENT	#39503 TERTIARY EFFLUENT
AMMONIA - N (μg/1)	60	60	60	120
NITRITE - N (μg/1)	5	5	4	8
NITRATE - N (mg/1)	42	40	44.1	42
TOTAL P (mg/1)	12	0.357	12	0.357
ORTHOPHOSPHATE - P (mg/1)	12	0.189	12	0.231
pH	7.1	7.4	7.3	7.3
TOTAL ALKALINITY (mg/1)	64	54	75	75
BICARBONATE ALKALINITY (mg/1)	64	54	75	75
TOTAL FE (μg/1)	600	80	360	80
NTA (mg/1)	0.1	0.1	0.1	0.1

effluents.

Lake Tahoe NTA Culture (LTC-V-70), 6-13 August 1970 - Water was collected at the index station at a depth of 20 m on 6 August. The results of chemical analyses performed on water samples collected at the same place on three dates before and after 6 August are listed below:

	3 Aug.	11 Aug.	15 Aug.
Total Phosphorus ($\mu g\ P \cdot l^{-1}$)	4.5	---	4.0
Nitrate ($\mu g\ N \cdot l^{-1}$)	3.0	---	2.5
Total Iron ($\mu g\ Fe \cdot l^{-1}$)	7.0	---	---
Inorganic Carbon ($mg\ C \cdot l^{-1}$)	---	10.16	---

Culture flasks were incubated *in situ* for a seven day period and removed for daily filtrations of 50 ml aliquots. Dilutions of the NTA stock solution and series #29500 - 29503 sewage effluents from 0.01% to 10.0% were studied.

Castle Lake tests also included one *in situ* and one laboratory incubation experiment.

Castle Lake NTA Culture (CASL-1-70), 27 Sept.-3 Oct. 1970 - Water from a depth of 3 m was collected at the deep station (35 m) on 27 Sept. The following water chemistry data was obtained:

Nitrate - N	$<1.\ \mu g \cdot l^{-1}$
Soluble PO_4-P	$<0.5\ \mu g \cdot l^{-1}$
Total P	$3.1\ \mu g \cdot l^{-1}$
Total Fe	$37.\ \mu g \cdot l^{-1}$
Inorganic C	$3.4\ mg \cdot l^{-1}$

Nineteen culture flasks were prepared containing 0.01%-1.0% dilutions of the NTA stock solution and sewage effluents #29500 - 29503. Cultures were incubated *in situ* at Castle Lake for seven days and removed for daily subsampling of 50 ml aliquots.

Castle Lake NTA Culture (CASL-2-70), 29 Oct.-4 Nov. 1970 -

On 25 Oct. water at a depth of 5 m was collected from the deep station. Chemical analyses were performed for the following elements:

Soluble PO_4-P	0.5 $\mu g \cdot l^{-1}$
Total Fe	16. $\mu g \cdot l^{-1}$
Nitrate-N	<1. $\mu g \cdot l^{-1}$
Inorganic C	4.1 $\mu g \cdot l^{-1}$

Eight different solutions were prepared in triplicate. Additions of the NTA stock solution at the 0.2%-7.0% levels and sewage effluents #39500 and #39502 at the 0.2% level were made. These samples were incubated in the Davis laboratory for seven days.

All three Clear Lake experiments were incubated at the laboratory at Davis under controlled light and temperature conditions for seven-day periods.

Clear Lake NTA Culture (CLC-1-70), 17-23 Sept. 1970 -

Water was collected 15 Sept. at the raft station using a sampler which isolated a continuous column of the top 3 m of water. Water chemistry analyses and measurements of physical parameters yielded the following results:

Soluble PO_4-P	390. $\mu g \cdot l^{-1}$
Total soluble P	404. $\mu g \cdot l^{-1}$
Total P	431. $\mu g \cdot l^{-1}$
Total Fe	2.40 $mg \cdot l^{-1}$
Inorganic C	25.3 $mg \cdot l^{-1}$
Nitrate - N	15. $\mu g \cdot l^{-1}$
pH	8.75
Temperature	20.8°C
Secchi depth	0.33 m
Depth of 1% light transmission	0.92 m

Eleven different solutions were prepared in duplicate. These included

0.1%, 1.0%, 5.0%, and 10.0% dilutions of the stock NTA solution and 0.2% dilutions of the #29500 - 29503 sewage effluents.

Clear Lake NTA Culture (CLC-2-70), 13-19 Oct. 1970 -

Water was collected 3 Oct. at Corinthian Bay and stored nine days before use. No chemical analyses were performed. Culture flasks were incubated for two days at ~22°C in a fume hood under fluorescent lighting. They were then transferred to an incubator at 17°C under improved lighting conditons for the remaining five days. Sewage effluents from the #39500 - 39503 series were used.

Clear Lake NTA Culture (CLC-3-70), 29 Oct.-4 Nov. 1970 -

Water was collected at a depth of 0.5 m from the raft station on 27 Oct. Sample collection followed by one week the first rainfall of the season. The autumn bloom of *Aphanizomenon* which had initiated approximately one month earlier was still in evidence. A marked increase in nitrate concentrations over that of CLC-1-70 was observed.

Soluble PO_4-P	303. $\mu g \cdot l^{-1}$
Total P	316. $\mu g \cdot l^{-1}$
Total Fe	2.62 $\mu g \cdot l^{-1}$
Nitrate - N	300. $\mu g \cdot l^{-1}$
Temperature	16.3°C

Results and Discussion

Lake Tahoe Cultures -

The bioassays of Lake Tahoe phytoplankton showed that NTA and the sewage effluents containing it generally stimulated ^{14}C uptake (Table 30). In the first experiment (LTC-IV-70) all additions of secondary and tertiary effluents both with and without NTA were stimulatory. At the end of the four day study, the cultures with effluents containing NTA at the 2×10^{-3}% and 2×10^{-4}% levels showed more assimilated ^{14}C

TABLE 30. EFFECTS OF NTA AND SEWAGE EFFLUENT ADDITIONS ON LAKE TAHOE WATER

SUBSTRATE ADDED		% STIMULATION(+) OR INHIBITION(-) VS. CONTROL (LAST DAY OF EXPERIMENT)	
		LTC-IV-70	LTC-V-70
$2 \times 10^{-4}\%$	TERTIARY EFFLUENT	+59	+12
$2 \times 10^{-3}\%$		+9	+17
$2 \times 10^{-2}\%$		+117	+36
$2 \times 10^{-4}\%$	TERTIARY EFFLUENT + NTA	+100	+35
$2 \times 10^{-3}\%$		+13	+16
$2 \times 10^{-2}\%$		+99	+21
$2 \times 10^{-1}\%$		---	+61
$2 \times 10^{-4}\%$	SECONDARY EFFLUENT	+14	-9
$2 \times 10^{-3}\%$		+20	-35
$2 \times 10^{-2}\%$		+62	+4
$2 \times 10^{-4}\%$	SECONDARY EFFLUENT + NTA	+34	+24
$2 \times 10^{-3}\%$		+27	+48
$2 \times 10^{-2}\%$		+54	+57
$2 \times 10^{-1}\%$		---	+85
0.01%	NTA STOCK SOLUTION	-10	+21
0.1%		+37	+25
1.0%		+37	+58
10.0%		---	+48

than did those containing the same concentration of effluents without NTA. At the highest concentration of 2 x 10^{-2}%, the reverse situation was observed with this level producing definite inhibition. Additions of the NTA stock solution were stimulatory at the 0.1% and 1.0% levels while the 0.01% (0.344 g NTA·l^{-1}) showed no significant change from control values.

The second Lake Tahoe experiment (LTC-V-70) also included additions of NTA and sewage effluents at the 2 x 10^{-1}% level. Incubation for this test was carried out *in situ* over a seven day period. Additions of tertiary effluents with and without NTA were all stimulatory to carbon-14 uptake in the concentration range tested (2 x 10^{-4}% to 2 x 10^{-1}%). All secondary effluent additions with NTA were also stimulatory; lack of stimulation was exhibited only by the two most dilute solutions of secondary effluent which did not contain NTA. Additions of the NTA stock solution at 0.01%, 0.1%, 1.0%, and 10.0% levels also increased ^{14}C uptake with greatest photosynthetic enhancement shown at the 1.0% level of addition (34.4 μg·l^{-1} NTA).

Castle Lake Cultures -

Of all our experiments, the *in situ* Castle Lake culture (CASL-1-70) produced the most significant stimulatory effects with NTA addition (Table 31). All tertiary effluent additions gave positive responses, but those which contained NTA were the most stimulating. For the samples with secondary effluents added, only the ones with NTA were stimulatory. The cultures responded with increased ^{14}C uptake only to the addition of the stock NTA solution at the 0.01% level. In the range tested, the higher concentrations were not found to be stimulatory.

The second Castle Lake experiment (CASL-2-70) was incubated in a laboratory at Davis. All of the eight different cultures spiked with NTA or secondary sewage effluents (#39500 and 39502) responded with increased

TABLE 31. EFFECTS OF NTA AND SEWAGE EFFLUENT ADDITIONS ON CASTLE LAKE WATER

SUBSTRATE ADDED		% STIMULATION (+) OR INHIBITION (-) VS. CONTROL (LAST DAY OF EXPERIMENT)	
		CASL-1-70	CASL-2-70
2 x 10^{-4}%	SECONDARY EFFLUENT	---	---
2 x 10^{-3}%		-2.5	---
2 x 10^{-2}%		-32	---
2 x 10^{-1}%		---	+175
2 x 10^{-4}%	SECONDARY EFFLUENT + NTA	+1430	---
2 x 10^{-3}%		+500	---
2 x 10^{-2}%		+920	---
2 x 10^{-1}%		---	+140
2 x 10^{-4}%	TERTIARY EFFLUENT	+550	---
2 x 10^{-3}%		+890	---
2 x 10^{-2}%		+1320	---
2 x 10^{-1}%		---	---
2 x 10^{-4}%	TERTIARY EFFLUENT + NTA	+1050	---
2 x 10^{-3}%		+740	---
2 x 10^{-2}%		+1430	---
2 x 10^{-1}%		---	---
0.01%	NTA STOCK SOLUTION	+1240	---
0.1%		-21	---
0.2%		---	+7
0.6%		---	+33
1.0%		+11	+35
3.0%		---	+20
7.0%		---	+43

^{14}C uptake over the control after seven days of incubation (Table 31). The secondary effluents with and without NTA were more effective at enhancing ^{14}C assimilation than NTA alone.

Clear Lake Cultures -

All three Clear Lake NTA culture experiments were performed under light and temperature-controlled conditions at Davis. Effects from the addition of NTA and sewage effluents were less noticeable and more variable in nutrient-rich Clear Lake water compared to Lake Tahoe or Castle Lake. Variations in the results from these three experiments may be explained on the basis of significant changes in phytoplankton and chemical composition of Clear Lake water during the period tested. Further, the filamentous bluegreen algae (Aphanizomenon) clumps and therefore provides more sampling error than the more dilute Castle and Tahoe populations.

Greatest positive responses to NTA were observed for the first Clear Lake test (CLC-1-70) (Table 32). Additions of the 5.00 mg $Na_3NTA \cdot H_2O \cdot 1^{-1}$ stock solution at 0.1%, 1.0%, 5.0%, and 10.0% levels stimulated ^{14}C assimilation as did the two sewage effluents containing NTA. The highest stimulation was exhibited by the medium containing the NTA solution at the 1.0% level. At the end of the seven-day incubation period, the NTA-free sewage effluents (#29500 and 29502) both showed slight inhibition at the 0.2% level although definite stimulation had been observed for the first six days.

Because of the possibility of non-photosynthetic adsorption of ^{14}C in experiments of this type (Goldman and Mason 1962), both the 0.45 μ Millipore(R)-filtered lake water plus 1.0% NTA solution and the unfiltered autoclaved lake water plus 1.0% NTA solution were checked for ^{14}C uptake during the seven-day period. Carbon-14 uptake by these adsorption controls was found to be negligible.

TABLE 32. EFFECTS OF NTA AND SEWAGE EFFLUENT ADDITIONS ON CLEAR LAKE WATER

SUBSTRATE ADDED	% STIMULATION (+) OR INHIBITION (-) VS. CONTROL (LAST DAY OF EXPERIMENT)	
	CLC-1-70	CLC-2-70
0.2% SECONDARY EFFLUENT	-2	+18
0.2% SECONDARY EFFLUENT + NTA	+40	+14
0.2% TERTIARY EFFLUENT	-3	+1
0.2% TERTIARY EFFLUENT + NTA	+41	+6
0.1% NTA STOCK SOLUTION	+22	---
0.2%	---	+33
1.0%	+50	---
2.0%	---	+9
4.0%	---	+5
5.0%	+21	---
10.0%	+34	0

At the completion of the second Clear Lake test (CLC-2-70) all samples showed stimulation of ^{14}C uptake over the controls (Table 32). Highest positive responses were found for the NTA stock solution at the 0.2% level (+33%), 0.2% secondary effluent (+18%), and 0.2% secondary effluent plus NTA (+14%). The culture flasks containing additions of the NTA stock solution showed initial inhibition at the 4.0% and 10.0% levels. After what appeared to be acclimatization periods of five and seven days, respectively, the organisms in these cultures were able to assimilate ^{14}C as well as the controls. In contrast, the more dilute NTA solutions showed immediate accelerated rates to ^{14}C assimilation.

The third Clear Lake test (CLC-3-70) was unique in that neither inhibition nor stimulation could be attributed to the added NTA or sewage effluents. No really definite trends were observed when compared to the control; the variations observed were within the limits of experimental error. The absence of a measurable effect suggests that an entirely adequate supply of nutrients was present in the natural lake water. Except for a twenty-fold increase in the nitrate-nitrogen concentration, all chemical parameters measured were very similar to those for CLC-1-70. This definitely suggests the involvement of nitrogen in the earlier stimulation recorded and follows the upward shift in the nitrogen-to-phosphorus ratio which preceded this experiment.

Conclusions

The experimental results reported here demonstrate the stimulatory effect of effluents containing NTA on the photosynthetic activity of natural phytoplankton populations. This is not surprising when one considers that the three lakes assayed all tend to be nitrogen deficient, at least during the period when these experiments were conducted. Further, Lake Tahoe is a known iron deficient lake (Goldman 1964) which may be affected by chelation. Chelation by NTA, which may suppress inhibitory levels of copper in Clear Lake, may be partly responsible for the high stimulation by NTA in Clear Lake phytoplankton.

SECTION VIII

MICROBIAL HETEROTROPHIC GROWTH IN LAKE TAHOE

THE REGULATION OF HETEROTROPHIC ACTIVITY BY ENVIRONMENTAL FACTORS AT LAKE TAHOE (This section is based on a Ph.D. dissertation by Hans W. Paerl).

Introduction and General Description

Studies of algal primary productivity on a spatial and temporal basis indicate that Tahoe's extremely oligotrophic state is in delicate balance. The noted response to even minute additions of nutrient originating mainly from sewage influx and land disturbance has confirmed that affected areas of Tahoe are assuming a more common trophic state, that of normal oligotrophy or even mesotrophy. In these areas of the lake proper, as well as man-made impoundments, noticeable changes in the rates of primary productivity, or fixation of inorganic carbon, are currently being detected (Goldman, Moshiri, and Amezaga 1972). With regard to the microbial community as a whole, however, this is only part of the picture of community change. The biological, chemical, and physical parameters regulating, or limiting, the bacterial incorporation and breakdown of organic carbon (heterotrophy) are also changing in certain areas of the lake. It was the objective of this study to differentiate between predictable temporal fluctuations in heterotrophic activity in unaffected sections of Lake Tahoe and fluctuations regulated to some extent by nutritive input attributable to man's activity in the watershed. Furthermore, assessment of particular modes of bacterial stimulation were considered as they relate to the sources of stimulation in the Tahoe watersheds. Silts, composed of inorganic materials such as mica and feldspar and particles of detritus (non-living organic particulate matter), are currently entering Lake Tahoe at accelerated rates. Disturbances associated with land development are largely responsible for this accelerated nutrient input. At South Lake Tahoe where 40% of Tahoe's surface runoff enters by way of Trout Creek and the Upper Truckee River, silt discharge is substantial. Approximately 30,000 tons of sediment was deposited by this river system in 1969 (State of California Resources Agency 1969). A combination of bioassay methods in the laboratory with in situ sampling in the Upper Truckee influx area of Lake Tahoe was used to link siltation originating from this watershed with increased microbial growth in the influx area. Methods of in situ sampling as well as bioassays were developed to aid in the detection of stimulatory sources and their influence on the waters of Lake Tahoe. The methods presented here in published form (see literature cited) have potential application to the full range of aquatic ecosystems from oligotrophic to eutrophic.

The stimulatory effects of several parameters (temperature, nutrients, bacterial biomass) on heterotrophic activity in Lake Tahoe were measured from 1970 through 1971 on an uninterrupted basis. Results from these studies are summarized in a Ph.D. thesis (Paerl 1973a) and several publications which have resulted from the study. Abstracts of these publications are attached to this report (Paerl and Goldman 1972a, b; Paerl 1973a; Holm-Hansen and Paerl 1972; Goldman et al. 1973, 1974).

Methods

All methods used in this research are included in the above publications cited.

Results and Discussion

Judging from heterotrophic responses to terrigenous as well as utogenic (primary production) input it is quite clear that organic carbon is the factor most limiting to heterotrophic growth. Because of the heterogeneity and imbalance of nutrients brought about by different kinds of nutritive inflow, however, organic carbon is not limiting in all sectors of the lake. For instance, inorganic phosphorus additions to midlake water consistently increase rates of heterotrophic growth. This indicates that in midlake and in deep waters there appears to be a chronic shortage of phosphate which is limiting to a community deriving its main energy source from organic substrates. A review of the nutrient concentrations (both organic and inorganic) indicates that it is not unusual for inorganics to limit a heterotrophic community (Paerl 1973a).

Under nutrient conditions that prevail in most of Lake Tahoe, temperature parallels heterotrophic activity (Fig. 50). This is probably not surprising since metabolic activity and growth have long been known to be closely related to temperature changes. Respiration is also affected by temperature changes (Zobell 1946). Zobell proposes that under the influence of increased water temperatures, the amount of carbon fixed by heterotrophic uptake may well be excreted as CO_2 through respiration. In that case, no net increase in biomass would be noted. Zobell's hypothesis could not be substantiated by the present studies. In fact, some opposite results were obtained. Studies using ATP determinations of bacterial biomass reveal that biomass increases virtually simultaneously with temperature increases while nutrient levels (inorganic as well as organic) remain fairly constant. This suggests that some bacterial species in Lake Tahoe find increased temperatures advantageous in terms of increasing their total biomass during the summer months. This is mainly accomplished through changes in (1) bacterial diversity and

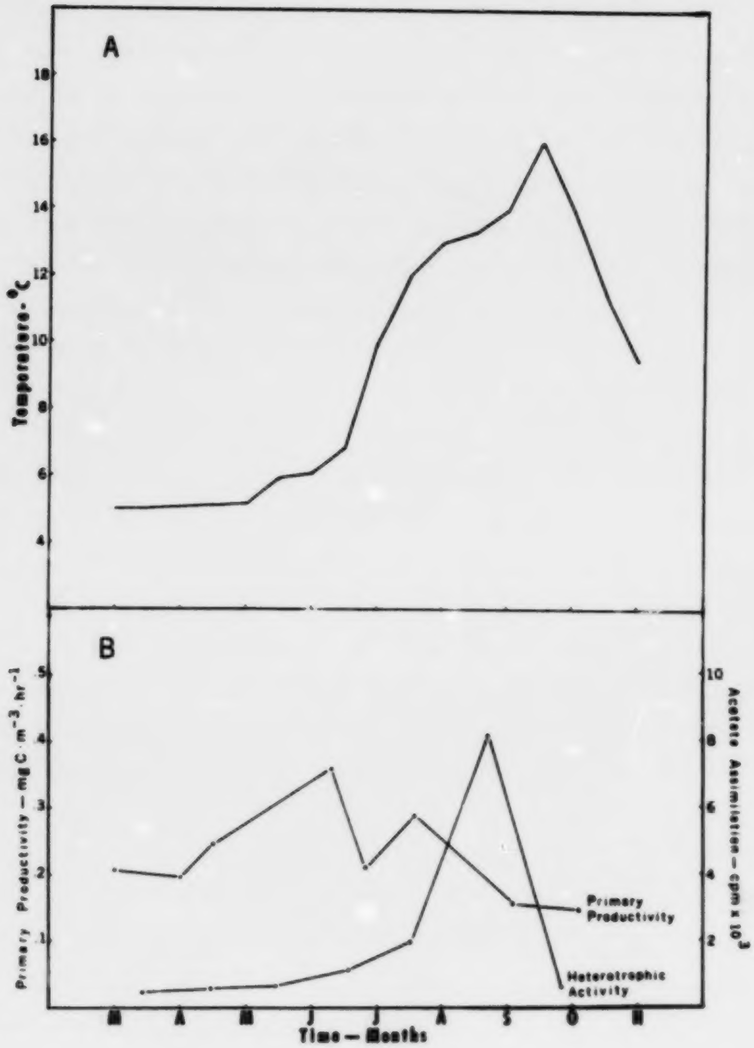


Figure 50. Seasonal temperature (A), and primary productivity and heterotrophic activity (B) at the Upper Truckee River station from March to November 1971. All samples were taken at 1.5 m depth.

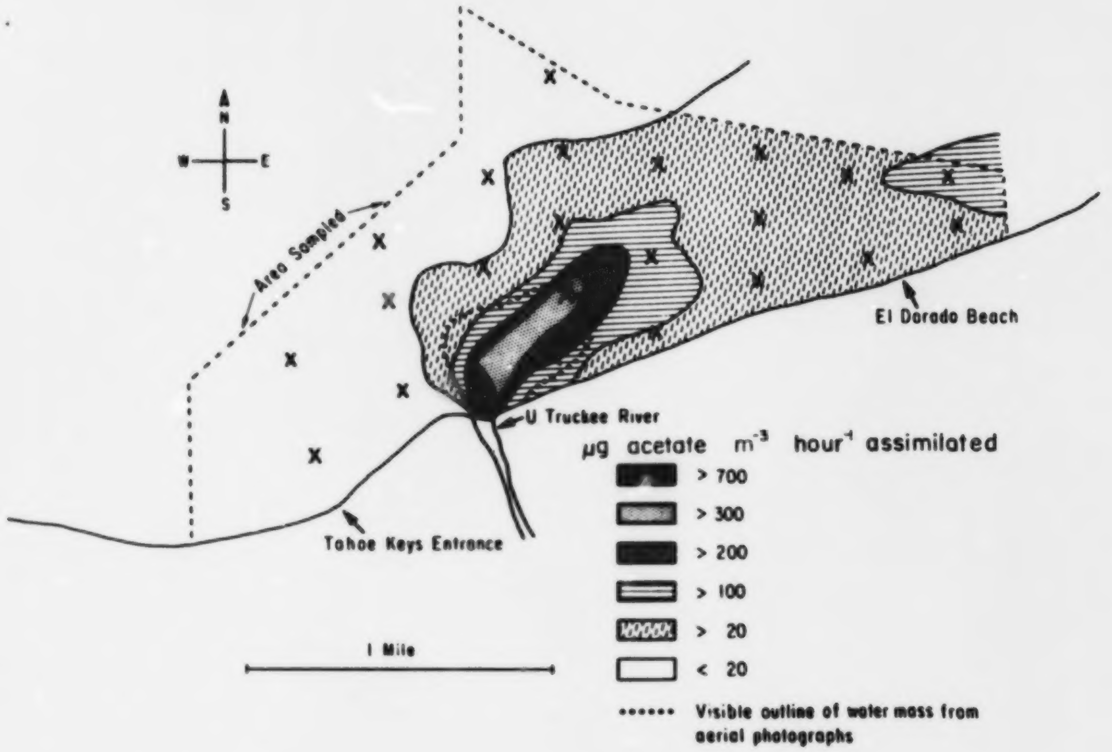
numbers, noticed in both direct and plate observations, and (2) changes in cell size, observed with the scanning electron microscope. Furthermore, under similar nutrient concentrations, bioassay experiments repeatedly gave higher rates of heterotrophy and accumulation of biomass in cultures incubated at elevated temperatures. These cultures also show rapid changes in bacterial morphology and diversity in response to temperature change. Thus, the relationships between nutrient limitation and heterotrophic response in terms of growth are very complex as water temperatures change, presumably due to changes in cell size or growth and diversity of species of bacteria.

Synoptic results of heterotrophic uptake assays are valuable in distinguishing seasonal patterns in heterotrophy regulated mostly by temperature from increased growth rates caused by nutritive input from the watersheds. Since temperatures at the synoptic stations (Paerl 1973a) were virtually the same during any one synoptic, the effect of variable nutrient concentrations (involving a complex nutrient regime) could be monitored. The synoptic data (Fig. 51) emphasize the impressive fertilizing effect of the Upper Truckee River (Paerl and Goldman 1972a, Paerl 1973a).

Heterotrophic Growth in Response to Siltation -

In areas receiving terrigenous input of particulate and dissolved nutrients, consistently higher rates of heterotrophy were noted as well as increased bacterial biomass, when compared to mid-lake areas. The stimulatory role of organic carbon and phosphorus as elucidated through bioassay experiments (Paerl and Goldman 1972b) has been discussed (Paerl 1973a) (Fig. 52). There is another factor stimulating bacterial growth. This is the total surface area present on all organic and inorganic particulate matter.

Earlier experiments have shown surfaces of sampling bottles to be highly



N
W
E
S
Area Sampled
El Dorado Beach
U Truckee River
Tahoe Keys Entrance
1 Mile
μg acetate m⁻³ hour⁻¹ assimilated
> 700
> 300
> 200
> 100
> 20
< 20
Visible outline of water mass from aerial photographs

Figure 51. Heterotrophic activity (μg acetate$\cdot$m$^{-3}\cdot$hr^{-1} assimilated) in the Upper Truckee River transect area on 30 July 1971. Sampling stations are indicated by a small cross. Acetate concentrations were 0.05 μg acetate$\cdot$l^{-1}. Note the visible outline of the Upper Truckee River water mass as it enters the lake.

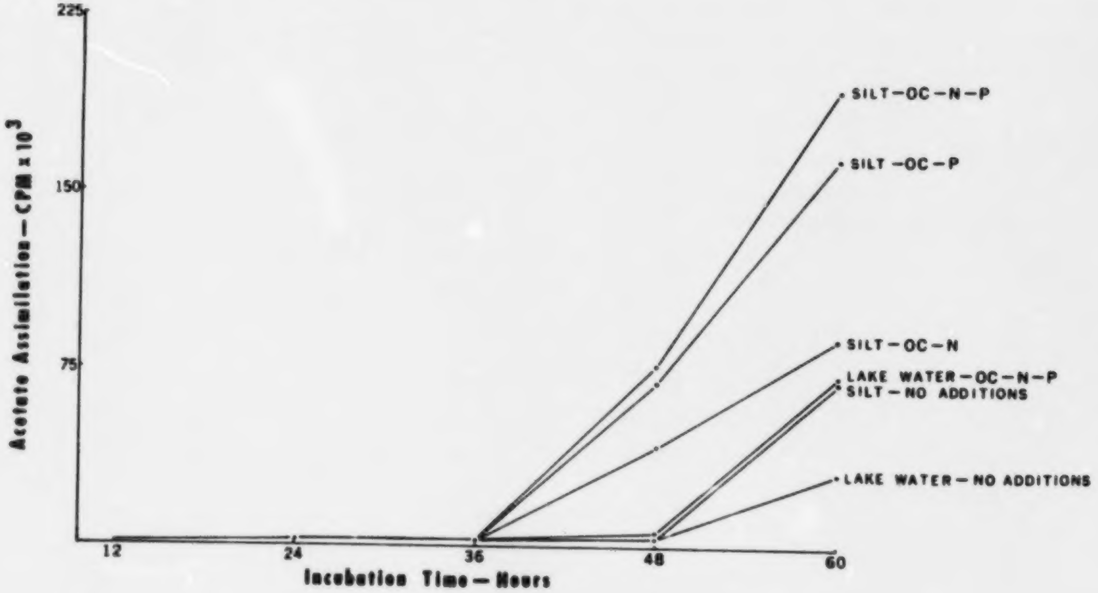


Figure 52. Heterotrophic bioassay of additions of nutrient-stripped silt in combination with organic carbon (100 μg/l as glucose), nitrate (10 μg/l), and phosphorus (12 μg/l) to Lake Tahoe water. Notice stimulatory effects of surface area in silt bioassays having similar nutrient concentrations as lake water without silt.

stimulatory to bacterial growth (Javornicky and Provesova 1963). Rodina has also discussed the role of particulate material in the formation of detritus, which he describes as a complex conglomeration of non-living organic matter interlaced and covered with decomposers, mainly bacteria and fungi (Rodina 1963). Because his study is based on light microscopy observations, difficulties arose in distinguishing bacteria from detrital matter. Paerl's own light microscopic observations (phase with oil immersion) indicate the task of separating non-living from living particulate matter is extremely difficult and at times impossible for the following reasons: (1) Staining techniques using erythrosin, methylene blue, and acridine orange were not specific (i.e., stains did not selectively stain living material). He observed mineral and organic particles, clearly non-living, that had incorporated or absorbed each of these stains. (2) Shapes of suspended solids in the Upper Truckee inflow area were very similar to bacterial shapes, and visual enumeration proved fruitless. Scanning electron microscopy (SEM) revealed that morphological distinction between detrital material and bacterial cells is subtle. SEM observations indicate that the extent of association of bacterial cells smaller than 1 μm with detritus is very difficult to quantify using light microscopy. Both SEM and freeze-etch electron microscopy observations of Lake Tahoe detritus show that associations of bacteria with detrital material commonly occur, and have a significant influence on estimates of total biomass (Paerl and Leonard unpublished). In contrast, others (Weibe, Johannes) with whom Paerl has discussed this problem have seen little association of bacterial cells with detrital matter in the Atlantic Ocean. These workers used light microscopy observation in reaching their conclusions.

Autoradiography proved to be very helpful in giving direct evidence that bacteria were associated with detritus in Lake Tahoe (for autoradiographic methods see Paerl and Goldman 1972a). Samples incubated with 2 - ^{14}C-acetate for periods up to four hours showed localization of radioactivity around detrital particles. Metabolic inhibition of the same water samples with 2, 4-dinitrophenol and subsequent incubation with the ^{14}C substrate reduced radioactivity by 80%. Such experiments left little doubt that live organisms, which are too small to detect or discriminate with light microscopy, were actively metabolizing organic carbon on detrital particles. When acid-hydrolyzed (nutrient-stripped) silts were added to mid-lake water samples, it was shown that bacterial activity and biomass were notably increased (Paerl 1973a). By providing a site for attachment or adherence even without nutritional value, silts are able to stimulate bacterial growth in Lake Tahoe.

Autoradiographs performed on these "inert" silt additions showed again that bacteria rapidly colonized such particles and soluble organic materials (in this case ^{14}C-acetate) accumulated on particles. The role of particulate material in stimulating bacterial growth in Lake Tahoe appears to be two-fold. A direct source of nutrition and attachment is provided by detritus and inorganic silts, since it has been shown that particulate material originating from inflow sources contains appreciable amounts of carbon, nitrogen, and phosphorus. Secondly it appears advantageous for bacteria to be attached to suspended material regardless of its nutritive nature, because organics and inorganics adsorb to this material.

The importance of this finding may be better amplified if Tahoe's oligotrophic nature is considered. In a low nutrient environment the growth of organisms capable of extracting and utilizing dissolved nutrients in trace concentrations is favored. One adaption has been found using SEM. Electron micrographs show that bacterial cell size in Lake Tahoe is very small compared to a more eutrophic lake such as Castle Lake, California. Thus the increased surface-to-volume ratios of small organisms is favored. In addition, a high incidence of bacterial attachment on suspended solids is evident (Paerl 1973b). In view of the capacity of this material to support bacteria utilizing dissolved substrates in trace concentrations, they form a kind of "dinner plate" for bacteria capable of adhering to particles. Much of the detritus of Tahoe is composed of decaying remnants of algae as well as zooplankton and, of course, the products of terrestrial erosion.

Results in Relation to Current Environmental Problems in the Tahoe Basin - Regardless of various intricate and still poorly understood mechanisms of nutrient release in Lake Tahoe, it should be stressed that bacteria are greatly involved. They are essential cyclers of organic substrates, nitrogen and phosphorus, acting upon these substrates and converting them to biomass. Bacteria in turn eventually release nutrients through death and autolysis. This is attributed to several limiting factors halting growth as well as through zooplankton and protozoan utilization of bacterial biomass (Sorokin 1966). An extremely important function of bacteria in aquatic ecosystems as shown here is to reintroduce organic and inorganic materials into living matter, thereby keeping them from rapidly piling up in the sediments largely unacted upon. Through their characteristics of high surface-to-volume ratios, capability for attachment, ability to take up a wide range of organic material, and rapid reproductive rates, aquatic bacteria are quick to take advantage of utilizable nutrients and either pass them on to higher levels of the food chain or release inorganic nutrients through death. These released inorganic nutrients have been shown to be the factors limiting algal growth in Lake Tahoe (Goldman and Armstrong 1969). It is therefore safe to assume that increases in algal and bacterial production go hand-in-hand with the process of eutrophication. The excellent spatial relationship of primary productivity and heterotrophic activity certainly substantiates this. Pockets of Lake Tahoe currently being affected by either high dissolved and/or particulate nutritive input, as exemplified by the Upper Truckee River inflow area, demonstrate this relationship. There exists, however, a distinct advantage in using bacterial activity as an indicator of sources of eutrophication in the Tahoe watershed. The means of bacterial stimulation, either due to sources of organic nutrition or sources of surface areas for bacterial attachment, can be directly related to particular sites of man's activity in the Tahoe basin. Algal stimulation appears to be more generally related to soluble levels. Soluble nutrient concentrations are more difficult to relate to current routes of nutritive input, because mineralization and chemical nutrient releasing processes have in some cases preceded the uptake of these nutrients by algae.

An example of current eutrophication trends at Lake Tahoe should illustrate the distinct advantage in using heterotrophic activity as an indicator. Approximately ten years ago, the input of nutrients from both septic tanks and sewage treatment plants was conclusively shown to increase the primary productivity of the lake (Goldman and Carter 1965). Algal growth response to this input of soluble nutrition proved to be an excellent indicator. This data was instrumental in initiating sewering all of the Tahoe watershed and exporting treated sewage to another watershed. Today, Tahoe is facing a distinctly different, and perhaps less reversible, route of nutritive input. Land disturbance and resultant siltation of streams leading into Lake Tahoe has become a prime threat to the lake's clarity. Silt plumes are evident year around in the Upper Truckee-Trout Creek inflow area (approximately 40% of Lake Tahoe's inflow source). During periods of heavy rainfall and snowmelt, other tributaries downstream from areas of development in the Tahoe basin also have silt plumes of varying intensity. Since silt addition to Lake Tahoe water consistently stimulates bacterial growth rates by offering both surface area for attachment as well as nutrition, a direct relationship linking land disturbance to aquatic bacterial growth rates can be measured. Interpretation of algal responses to siltation are complicated by the fluctating transparency of water containing suspended solids. Changes in transparency affect photosynthesis rates and thus primary productivity measurements in silty areas reflect integrated effects of nutritional status and transparency of the water samples.

There appears to be a better relationship of bacterial activity to sediment content of Lake Tahoe water. The effects of siltation can be measured at great distances from the immediate inflow area with the sensitive ^{14}C-acetate method. SEM observations on water samples taken from areas affected by siltation are helpful, since particular types of sediment (of both organic and inorganic nature) can be directly linked to sites of land disturbance through identification of either soil types or organic matter originating from stream mouths. Differential bacterial growth on sediments has been noted in samples obtained from the Upper Truckee inflow area. This means that some sites of land disturbance (in morphologically identifiable soil or vegetation areas) play a higher stimulation role to bacterial growth than others. In this manner, disturbance areas of the Tahoe watershed, to which increased bacterial growth in the lake is highly susceptible, can be "fingerprinted" morphologically. Such information should prove valuable to planning and environmental control agencies attempting to define and control sites of land disturbance and erosion threatening the water quality of Lake Tahoe.

SECTION IX

PRIMARY PRODUCTION OF PERIPHYTON AND PLANKTONIC ALGAE IN THE LITTORAL ZONE OF LAKE TAHOE

Introduction

Lake Tahoe has very little littoral zone for its size and only about 10% of the lake's primary productivity is accounted for in the littoral zone. The narrow band of shallow water has, however, great importance to the lake's biota and provides the main visual evidence of water quality to the largely shorebound populace. In the last decade there has been an alarming increase in the growth of attached algae. Diatoms and green algae flourish in the shallow waters of Lake Tahoe. Accumulation rates of these algae were measured at offshore stations anchored to the bottom with submerged floats holding a rack well above the bottom. Pyrex® glass cylinders, attached to the rack and exposed to periphyton invasion, were collected periodically and combusted in an induction furnace. Algal biomass was measured in terms of organic carbon. In general, the periphyton distribution in Lake Tahoe was found to be surprisingly uniform. In all probability this results from the circulation of nutrient-rich tributary water around the margins. Attached forms have the advantage of more water contact than planktonic forms, since the water passes over them rather than carries them along. Unsightly masses of periphyton algae break loose and surface in the spring. Their decay may be instrumental in triggering blooms of planktonic algae. The phytoplankton

TABLE 33. LAKE TAHOE PERIPHYTON SPECIES LIST, INCLUDING CELL VOLUMES

Periphyton species list compiled from microscopic examination of live and preserved samples on glass cylinders and rocks. Where cell volumes have been measured they are given in (-^{3}).

Chlorophyceae
- *Sphaerocystis schroeteri* (268)
- *Geminella ordinata*
- *Ulothrix* sp.
- *Bulbochaete* sp.
- *Pediastrum sculptatum*
    - *tetras* var. *tetraodon*
- *Mougeotia genuflexa*
- *Spirogyra* sp.
- *Zygnema* (sterile)
- *Cosmarium* sp. A
    - sp. B
- *Euastrum bidentatum*
- *Pleurotaenium* sp.
- *Staurastrum natator* (4350)

Euglenaceae
- *Euglena* sp.

Dinophyceae
- *Peridinium pusillum*

Chrysophyceae
- Dinobryon sertularia (900)

Bacillariophyceae
- *Cyclotella antiqua* (635)
    - *bodanica* (4778)
- *Melosira crenulata* (1209)
    - *varians* (4301)
- *Stephanodiscus astrea* (707)
- *Diatomella balfouriana* (660)
- *Tabellaria flocculosa* (2700)
- *Diatoma anceps* (1000)
    - *hiemale* (mesodon) (1060)
    - *vulgare* (3600)
- *Opephora americana*
- *Asterionella formosa* (480)
- *Fragilaria capucina* (140)
    - *crotonensis* (510)
    - *intermedia* (2500)
    - *pinnata* (175)
    - *vaucheriae var.*
        - *capitellata* (276)
- *Synedra actinastroides*
    - *ulna* (19200)
    - *ulna spathulifera*
- *Eunotia tenella* (590)
- *Achnanthes clevei* (350)
    - *flexella* (880)
    - *lanceolata* (420)

Bacillariophyceae (contd.)
- *Achnanthes microcephala*
    - *peragalli* (430)
- *Cocconeis placentula* (503)
- *Amphipleura pellucida* (4080)
- *Diploneis elliptica* (1781)
    - *oculata* (330)
- *Frustulia rhomboides* (7600)
- *Mastogloia smithii* (5184)
- *Navicula aurora* (14016)
    - *bacillum* (2000)
    - *cocconeiformis* (980)
    - *elginensis*
    - *pupula* (1000)
    - *radiosa* (1100)
- *Neidium hitchcockii* (14800)
- *Pinnularia biceps* (4980)
    - *rupestris* (18000)
- *Gomphoneis herculeana* (6831)
- *Gomphonema acuminatum* (610)
    - *parvulum* (350)
- *Amphora ovalis* (2500)
- *Cymbella cuspidata* (10000)
    - *lanceolata* (6000)
    - *prostrata* (15750)
    - *sinuata* (375)
    - *ventricosa* (1800)
- *Epithemia argus*
    - *sorex* (5125)
    - *turgida* (66000)
    - *zebra* (11520)
- *Rhopalodia gibba* (8000)
- *Denticula* (*elegans*)
- *Nitzschia linearis*
    - (*sigma*?)
- *Cymatopleura solea* (var?) (37370)
- *Surirella* (*didyma*) (13000)

Cyanophyceae
- *Oscillatoria tenuis*
- *Anabaena* (*variabilis*?)
- *Nostoc microscopicum*
- *Calothrix parietana*
- *Scytonema myochrous*
- *Lyngbya nordgardii*
- *Nephrocytium agardhianum*
- *Tolypothrix* sp.

Cryptophyceae
- *Cryptomonas reflexa* ?

population is very diverse with over 160 species. Eighty-six species of periphyton have also been identified in the lake (Table 53). As expected, some of the periphyton also occur in the phytoplankton.

The substrata in the littoral zone varies from fine sand to boulders. The surface water temperature ranges from 4.6°C in the winter to 19°C in the summer. Levels of nitrate, total phosphorus, and iron are very low all year round (less than 10 $\mu g \cdot l^{-1}$). In contrast, levels of silicon, so important for maintaining diatom populations, are of the order of 3 to 7 $mg \cdot l^{-1}$ $SiO_3^{=}$-Si (see Section V).

There are only a few isolated beds of macrophytes (*Anachous canadensis*, *Myriophyllum* sp., *Potomogeton crispus*) in the littoral zone of the lake with an abundance of chara, the fungus *Apostemidium guernisal*, and aquatic moss (Fissidens), together with luxuriant growths of filamentous periphyton extending to depths of about 100 m (Frantz and Cordone 1967). No attempt has yet been made to estimate the abundance or productivity of these littoral zone plants. A large population of the crayfish *Pacifastacus leniusculus* inhabit the littoral zone and may be effective in grazing the periphyton crop (Goldman and Amezaga 1974).

Methods

In 1968, 79 periphyton sampling stations were located around the lake (Goldman, Moshiri, and Amezaga 1972). In 1971 periphyton was studied at 17 stations. Each offshore station consisted of a wooden rack anchored to the bottom of the lake in 10 m of water (Fig. 53). The rack was held in place 5 m above the bottom by submerged floats. The station location was determined by triangulation on terrestrial landmarks. Pyrex^R glass tubing cylinders (40 mm length and 24 mm O.D.), used as substrates for periphyton growth, were held by test tube holders attached to the rack. Installation and retrieval of the cylinders was

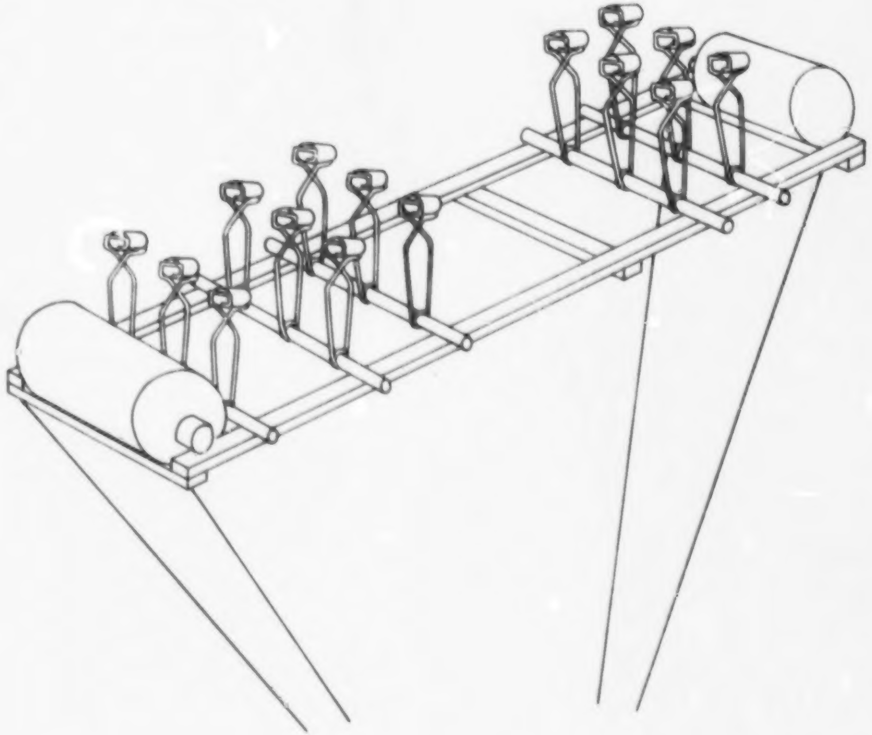


Figure 53. Schematic diagram of a periphyton station. Submerged floats hold the station in place 5 m above the bottom in 10 m of water.

done by SCUBA. Four samples were collected for each growth period. Three samples for total carbon measurement were placed in polyethylene vials and kept frozen until analysis. The fourth sample was placed in a glass vial filled with distilled water and fixed with Lugol's solution for periphyton species identification and enumeration.

A rapid method for the estimation of the carbon content in periphyton (Armstrong, Goldman, and Fujita 1971) was used to determine the amount of organic carbon that accumulated on the cylinder during the growth period. The method consists of combusting the sample in an induction furnace and measuring the evolved carbon as CO_2 with an infrared gas analyzer.

Preparation of the sample for periphyton identification and enumeration was initially accomplished by scraping the periphyton off the cylinder into its glass vial container. Later in the study, removal of periphyton from the cylinder was greatly facilitated by placing the glass vial containing the cylinder in an ultrasonic cleaner for five minutes. The sample was then shaken well to insure uniform distribution of the cells, a subsample was settled in an Utermohl chamber, and identification was done using a Wild M-40 inverted phase microscope.

Preliminary periphyton species identification was done from live samples, using glass cylinders that had been exposed at locations around the lake for 14 weeks between 24 June and 30 September 1970. The influence of the substrate on species composition was investigated by comparing glass cylinders and natural rock communities at several locations. Communities from both fresh and preserved samples on glass cylinders were compared at several locations to determine the effect of preservation.

Samples from some of the major tributaries to the lake were also examined for species composition.

Results

Periphyton Taxonomy -

Observations made on the cylinders incubated for 14 weeks during the summer of 1970 are shown in Figure 54. One Chlorophycean species (Mougeotia genuflexa) and six diatoms were found to be the dominant species. Mougeotia genuflexa occurred at all stations. Cylinders off the south-southwest shore of the lake were invaded by a relatively few dominant species (three or four) in comparison to the other stations (six dominant species), but their growth coverage was dense or very dense. Emerald Bay, which is partially isolated from the rest of the lake, had seven dominants. Fragilaria capucina was a dominant form only off the Upper Truckee River mouth and in Emerald Bay.

Results shown in Figure 55 are based on observations made on four to eight different samples at each station. These samples had been left in the lake for lengths of time varying from 2 to 23 weeks (overwinter) between 1 October 1970 and 2 May 1971. A rating system was devised to determine which species were dominant overall during the season at each sampled location. At each of the stations, for each sample available, the dominant species (dominant in number of cells present) were given a number of points in decreasing order of dominance (10 for the most dominant, 9 for the next dominant, 8 for the next, etc.). The total number of points for each species was computed, and the species that were most dominant during the season determined. The dominant species were those species that received a total number of points 25% or greater of the maximum total possible.

In winter, the number of dominant periphyton species remained substantially unchanged from those in the summer, yet the species composition changed almost completely (Fig. 55). The lake periphyton, in this winter-spring period, was dominated by seven diatom species. Synedra

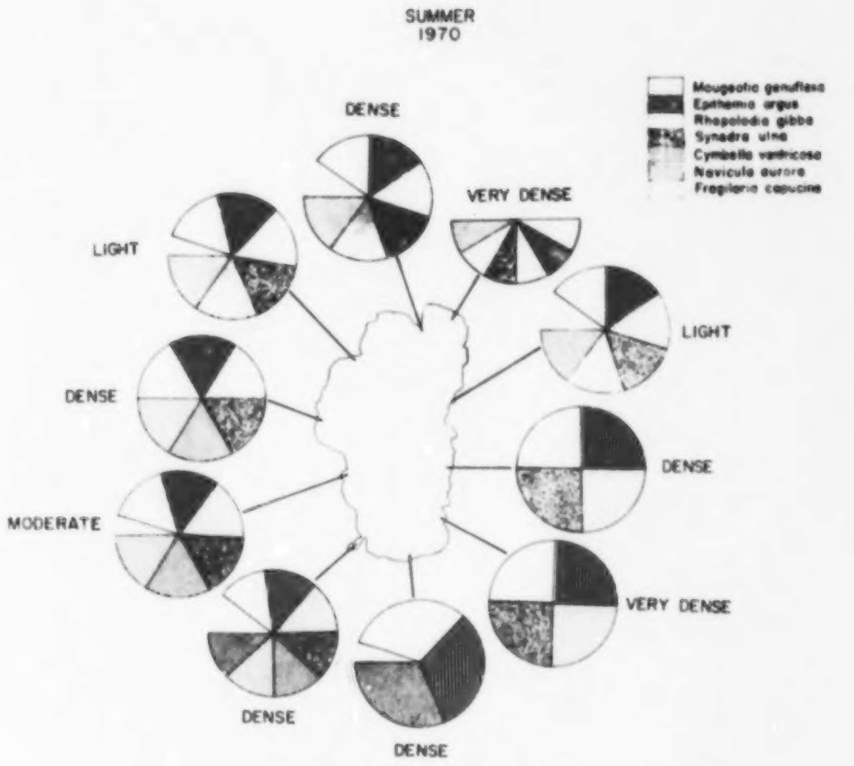


Figure 54. Dominant species of periphyton found on glass cylinders exposed in situ to periphyton invasion for 14 weeks between 24 June and 30 September 1970. The percent of the circle drawn represents the percentage of the slide that was covered by periphyton (50, 90, 95, or 100%). The relative density of growth is also indicated.

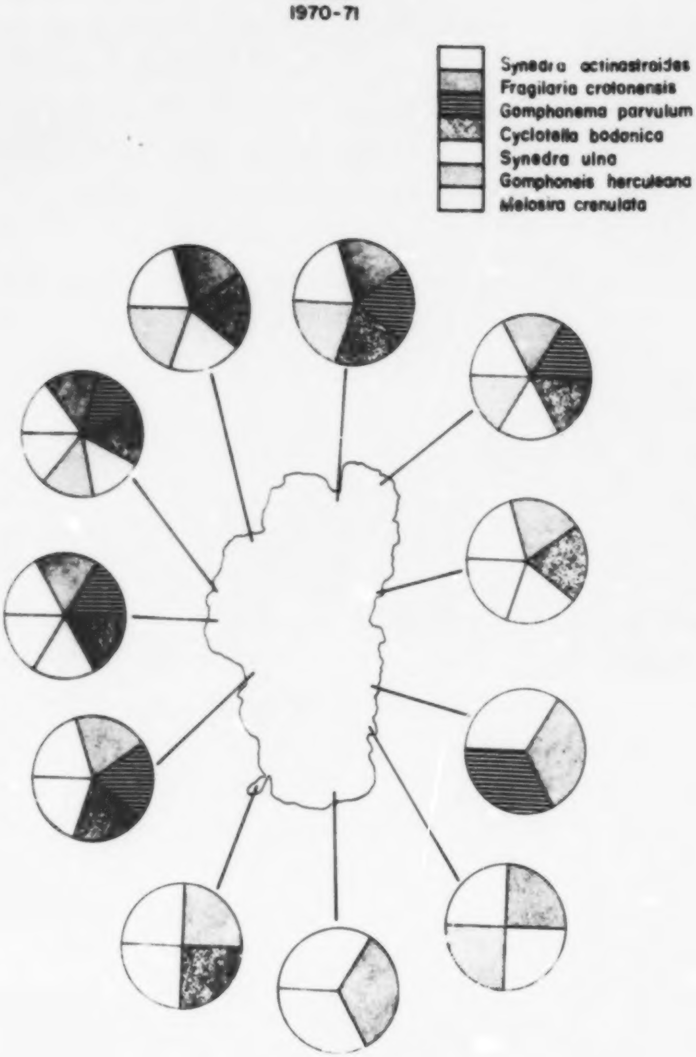

WINTER
1970-71
Synedra actinastroides
Fragilaria crotonensis
Gomphonema parvulum
Cyclotella bodanica
Synedra ulna
Gomphoneis herculeana
Melosira crenulata

Figure 55. Dominant species of periphyton found on glass cylinders exposed in situ to periphyton invasion for 2-23 weeks (over winter) between 1 October 1970 and 2 May 1971.

actinastroides was the most dominant at all stations. Fragilaria crotonensis was the second most dominant species, which was also found at all stations. The same pattern of low diversity (three or four species) that was observed in the summer persisted in the winter along the south-southwest shore. This zone is strongly influenced by the Upper Truckee River (Paerl and Goldman 1972a).

Observations of natural communities growing on rocks and piers near the offshore locations during our study of the shallower portion of the littoral zone showed, in addition, a dominance of Ulothrix in many of the areas around the lake and Gomphonema in some of them. Ulothrix is present in a number of tributaries.

Our preliminary comparison of communities growing on glass cylinders and communities growing on natural rocks seemed to evidence better blue-green growth (Calothrix, Tolypothrix, Nostoc) on rocks and better green growth (Mougeotia, Zygnema, Spirogyra) on glass, while diatoms grew well on either substrate. Later study indicated that glass was readily colonized by a large variety of algae. It was felt that rather than the substrate difference, differences in depth, current, and light were primarily responsible for the observed difference in colonization. Fresh samples were essential for accurate identification to the species level and Lugol's solution was found adequate as a preservative for subsequent enumeration.

Periphyton Production -

Periphyton growth around the margins of the lake was measured at the submerged stations described in Methods. Since each was located offshore at a depth of 10 m, the distance from the shore was quite variable. The highest growth rates were recorded near stream mouths where human activity is greatest, except in the vicinity of the largest tributary, the Upper Truckee River (Fig. 56). The shallow shelf there necessitated

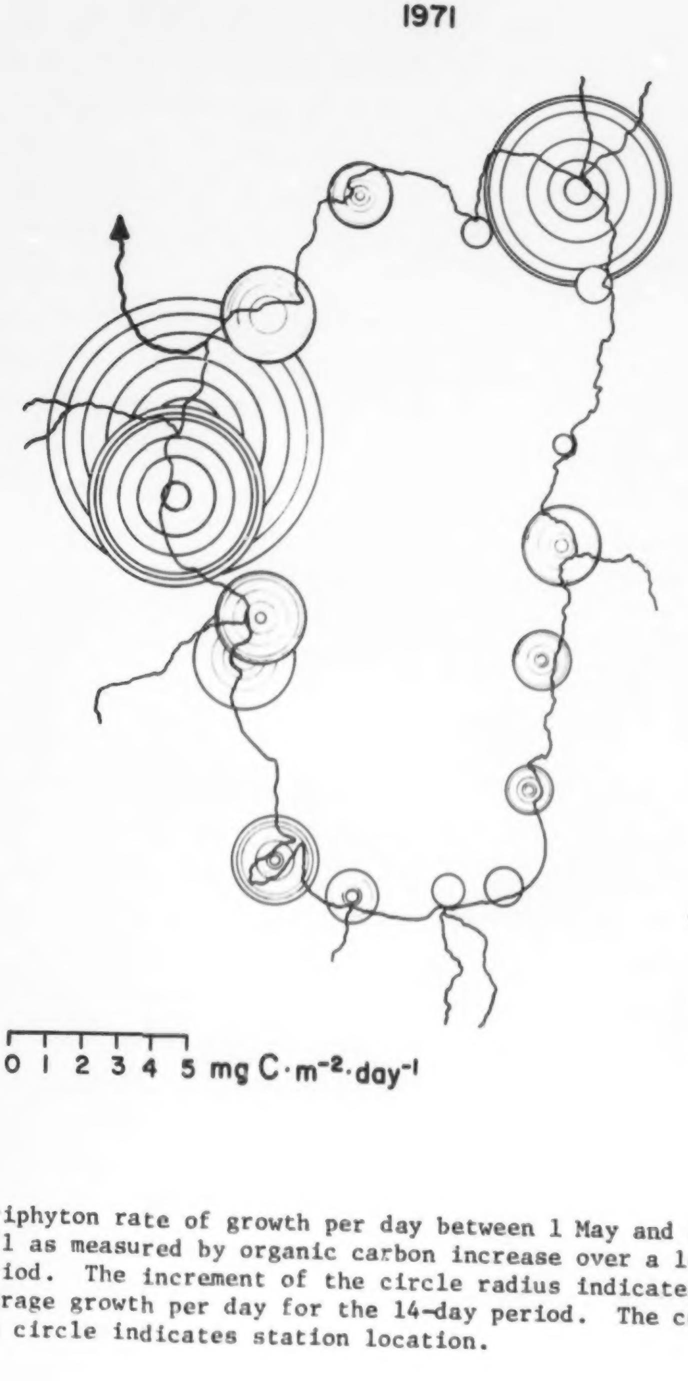


Figure 56. Periphyton rate of growth per day between 1 May and 15 July 1971 as measured by organic carbon increase over a 14-day period. The increment of the circle radius indicates the average growth per day for the 14-day period. The center of the circle indicates station location.

placement of periphyton stations 700 to 1200 m from the stream mouth to avoid loss of stations. This remote placement was not necessary off Ward Creek which, together with the Incline Creek location (partially contained by Crystal Bay), showed the highest increments of growth. In general, slower growth occurred in areas of least tributary influence such as along the sparsely populated east shore.

Rate of growth of periphyton in 1968 varied from 0.094 mg C·m^{-2}·day^{-1} north of Skunk Harbor between 20 July and 18 August to 2.228 mg C·m^{-2}·day^{-1}, 70 yards offshore north of Sand Harbor between 15 and 23 July. Periphyton growth was found to be a function of both the location and the time of incubation period (Fig. 57). After completing a matrix of 17 stations and five incubation periods in 1968, results were averaged to give one average value of rate between 28 March and 18 September 1968 (Fig. 57). These results vary between 0.343 mg C·m^{-2}·day^{-1} northeast of the Upper Truckee River to 1.010 mg C·m^{-2}·day^{-1} south of Tahoe City.

The average daily amount of periphyton growth on the bottom of the entire lake in 1968 was estimated by using the results from growth per day at each station as measured in organic carbon per square meter. Each station was chosen to be representative of a section of the littoral zone delimited by the shoreline, the depth of 100 m, and the distances halfway to the next stations. The periphyton production for that section was obtained by multiplying the surface area (determined by planimetry) by the amount of production at the corresponding station. The sum of the production of these sections gave the estimate of the total production of periphyton per day for the lake. The carbon content of algae was estimated to be 13% of the total fresh weight of the algae. On that basis, the average total fresh weight of periphyton added daily to the bottom of the lake (by photosynthesis on the bottom surface only) was found to be about 576.8 kg. This was an under-estimate of the average daily

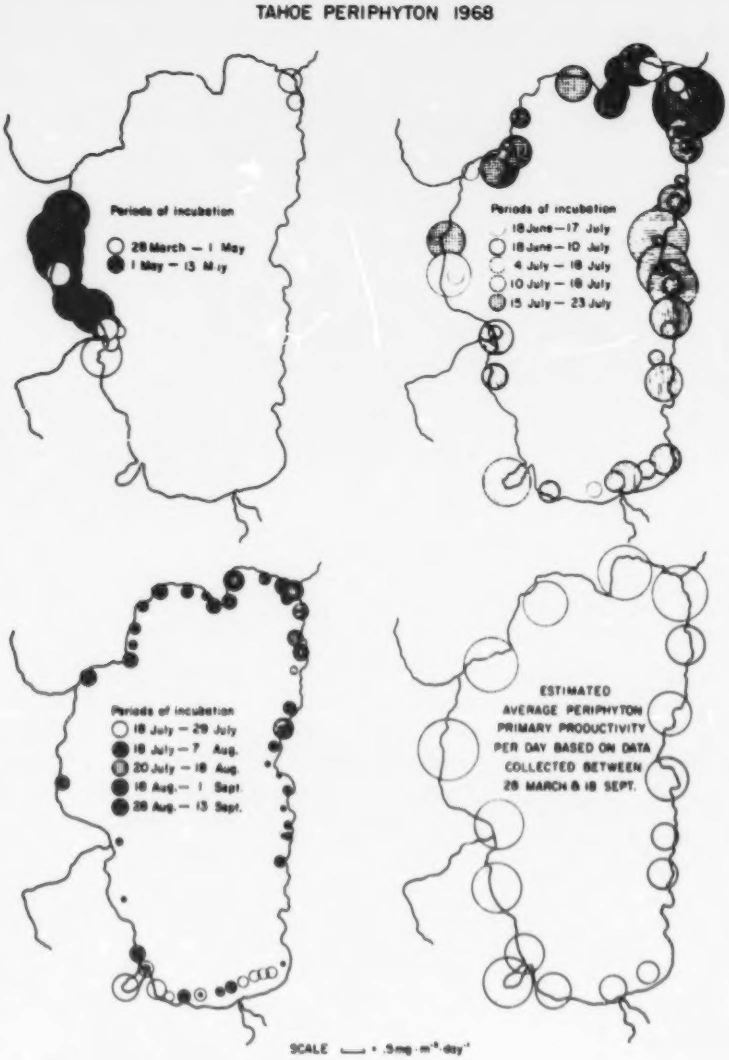

TAHOE PERIPHYTON 1968
Periods of incubation
○ 28 March — 1 May
● 1 May — 13 May
Periods of incubation
18 June — 17 July
○ 18 June — 10 July
4 July — 18 July
○ 10 July — 18 July
▨ 15 July — 23 July
Periods of incubation
○ 18 July — 29 July
● 18 July — 7 Aug.
● 20 July — 18 Aug.
● 18 Aug. — 1 Sept.
● 28 Aug. — 13 Sept.
ESTIMATED
AVERAGE PERIPHYTON
PRIMARY PRODUCTIVITY
PER DAY BASED ON DATA
COLLECTED BETWEEN
28 MARCH & 18 SEPT.
SCALE — = .5mg·m⁻²·day⁻¹

Figure 57. Periphyton rate of growth per day between 28 March and 18 September 1968 as measured by organic carbon increase over various time periods. The circle radius indicates the average growth per day for the time of incubation. The center of the circle indicates station location.

bottom growth of periphyton, since no correction was made to account for the irregularity of rock surfaces. Fox, Odlaug, and Olson (1969) found in western Lake Superior that, "after forty-six days of regrowth on artificially denuded rocks in Stony Point Bay, the growth level was approximately eighteen percent of that occurring naturally." Assuming this result valid for Lake Tahoe would have meant that there are about 147,397 kg (fresh weight) of periphyton in Lake Tahoe (about 147 metric tons). For purposes of comparison, the biomass of planktonic algae was calculated by averaging biomass per square meter for the three synoptic dates, which resulted in an estimate of 2,180 metric tons in the upper euphotic zone of the lake (Goldman, Moshiri, and Amezaga 1972).

The total production of periphyton per day for the entire littoral zone of Lake Tahoe was also estimated for 1971 (with a better seasonal coverage) in the same way as for 1968. This calculation was done for each of the dates in 1971 for which we had data available from periphyton cylinders left in the lake for a period of 14 days. The results plotted against time are shown in Figure 58. The growth rate increased steadily from early April until mid-May, leveled out through mid-June, and then declined through mid-July. This follows closely both the seasonal light curve and the influx of nutrients from the watershed.

Phytoplankton Productivity -

Phytoplankton productivity for the entire littoral zone of Lake Tahoe was based on in situ ^{14}C measurements made regularly at 12 depths between 0 and 100 m at our index station near Tahoe Pines (see Fig. 1). The phytoplankton productivity of the littoral zone relative to this index station was estimated from 13 synoptic measurements of primary productivity. Three synoptic surveys were done in 1968 and have been reported by Goldman, Moshiri, and Amezaga (1972); four were done in 1969, five in 1970, and one in 1971. They consisted of sampling 32 stations at several depths during a single night and incubating the samples

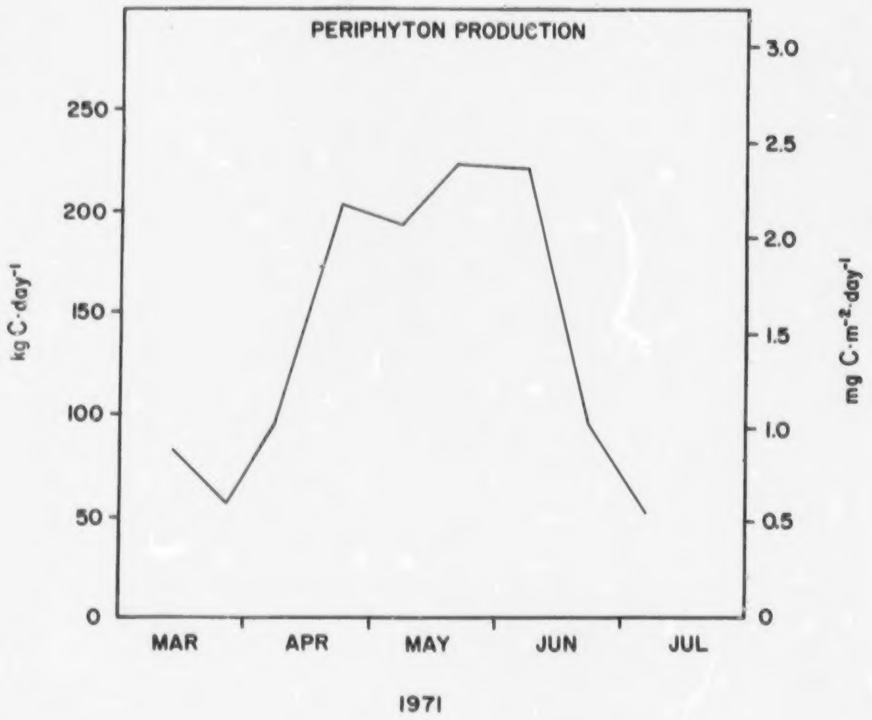


Figure 58. Periphyton production per day estimates for the littoral zone of Lake Tahoe. The left scale indicates the total production for the lake. The right scale indicates the average production per square meter for the lake obtained by dividing the total production value by the total surface area of the littoral zone.

in situ during the following light period. Eight of these station locations are pelagic, one is our regular index station, and the others are littoral. The average primary productivity for all 13 synoptics was calculated for all littoral stations to give one littoral value of mg $C \cdot m^{-2}$ and for all pelagic stations to give one pelagic value of mg $C \cdot m^{-2}$. The phytoplankton productivity of this littoral zone relative to the index station was calculated as a percentage of the average productivity of all littoral stations to the index station. The phytoplankton productivity in the pelagic zone relative to the index station was also calculated as a percentage. These estimated percentages were used to compute the average primary productivity of the phytoplankton on any day in the 12 layers of water in which the littoral zone had been divided corresponding to each depth of the index station. The sum of the phytoplankton productivity of the 12 layers of water was estimated to be the total phytoplankton productivity in the littoral zone that day. Results from these computations made for the period of time that corresponds to our periphyton production study are shown in Figure 59. The bimodal phytoplankton productivity curve peaked out in early June with the second peak occurring in August. This was in contrast to the periphyton biomass production curve (Fig. 58), which showed a single high plateau lasting for over two months between April and June.

Primary Production of the Littoral Zone vs. the Pelagic Zone - To compare the total primary production per day of the littoral zone of Lake Tahoe to that of the pelagic zone, the total biomass production per day of the periphyton (Fig. 58) was added to the total phytoplankton productivity in the littoral zone (Fig. 59). The biomass increments of periphyton growth and the rate measures of phytoplankton productivity are not strictly comparable. Combining them, however, should provide a good approximation of total littoral production. This was done by planimetering the areas of two week periods under each curve (Fig. 58 and Fig. 59), computing the corresponding mean value of carbon per day for each

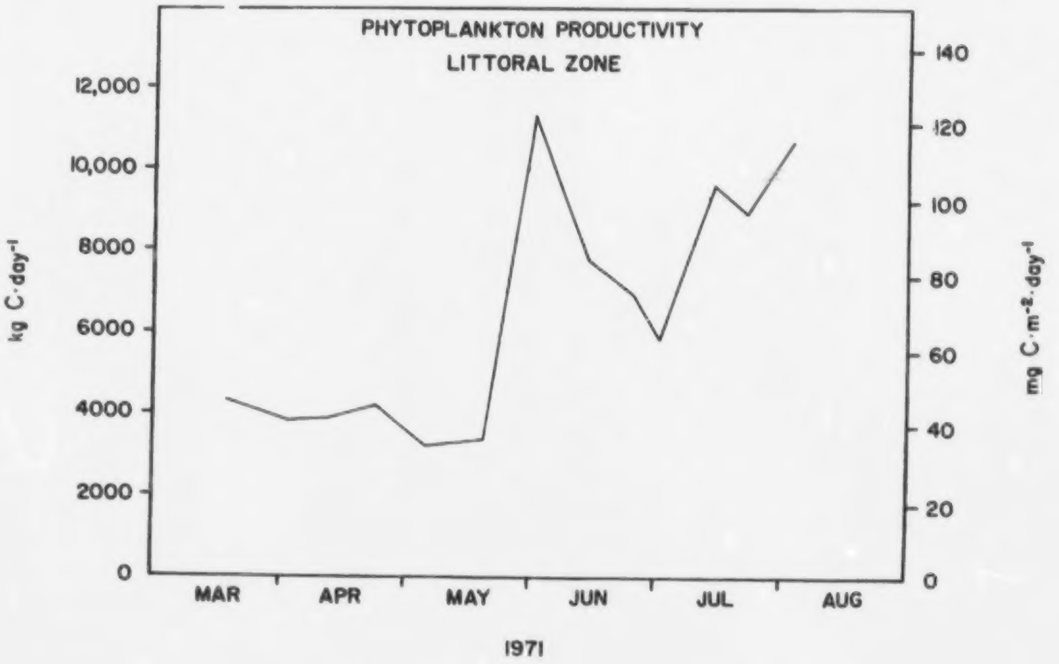


Figure 59. Phytoplankton productivity per day estimates for the littoral zone of Lake Tahoe.

community, and adding up these values. The primary productivity per day of the pelagic zone of the lake was computed by correcting the mean productivity per cubic meter at the index station by the percentage that the pelagic zone productivity represents and multiplying by the volume of water in the euphotic zone (0 to 100 m) of the pelagic zone. Results are shown in Fig. 60. We shall use the term primary production whenever we are referring to either biomass increments only or both biomass increments and ^{14}C measurements combined. We shall continue to use the term primary productivity when referring to ^{14}C measurements only.

By comparing the primary production curve of the littoral zone of Lake Tahoe with the pelagic productivity curve, we get a graphic impression of the relatively small littoral area involved as well as its contribution to the overall productivity of the lake. Only about 10% of the lake's production is accounted for by the combined phytoplankton productivity and periphyton production down to 100 m. Because of Lake Tahoe's morphometry, the pelagic zone contributes an order of magnitude more carbon to the lake in productivity than does the littoral zone.

Transect Measurements of Primary Productivity -
Primary productivity in the littoral zone was measured in 1968 with a series of transects. Computer contouring was utilized to display variation in productivity offshore (Goldman and Armstrong 1969). An average of four transects were used to construct each of the vertical profiles of phytoplankton productivity shown in Fig. 61. The Upper Truckee River, which provides 40% of Lake Tahoe's surface inflow, has a highly productive phytoplankton population per unit volume near shore decreasing steadily towards the pelagic zone. This decrease in productivity per unit volume with depth is inverse to the productivity per unit of surface area. The same is true for the Incline Creek transect except that the fertility of this partially enclosed area (Crystal Bay)

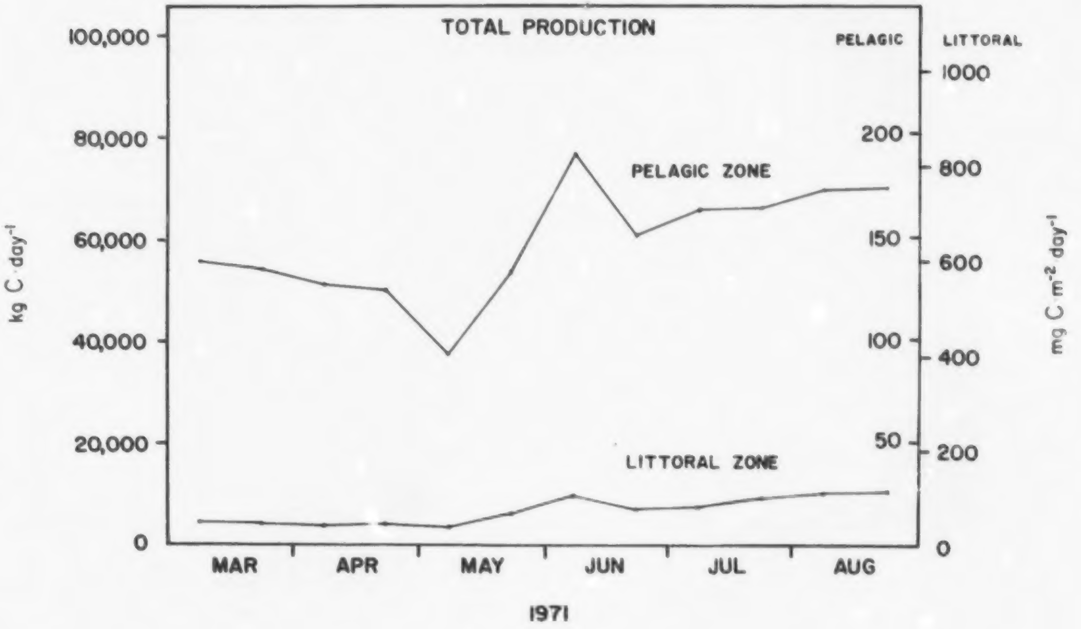


Figure 60. Total primary production per day of the littoral zone compared to the total productivity of the pelagic zone of Lake Tahoe.

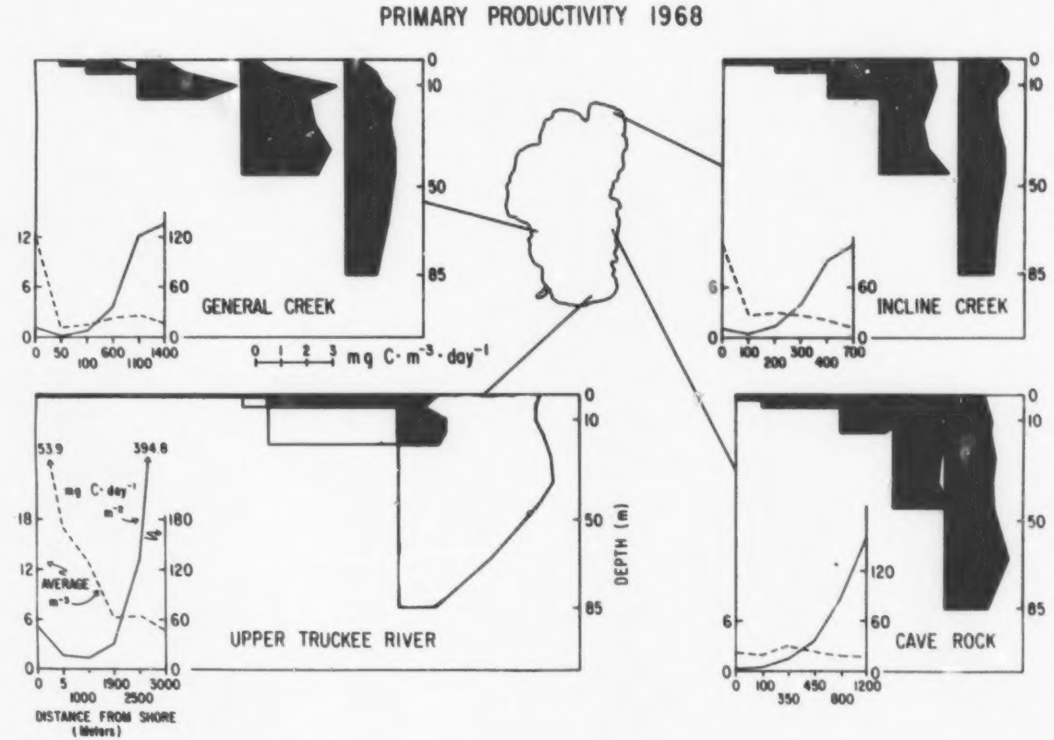


Figure 61. Phytoplankton primary productivity-depth profiles at various distances offshore of four littoral zone stations. Each point represents an average of four measurements taken on four different days between April and July 1968. The insert graph shows the variation of the total (mg C$\cdot$m$^{-2}\cdot$day^{-1}) and average (mg C$\cdot$m$^{-3}\cdot$day^{-1}) productivity as a function of the distance from shore.

is more uniform and probably reflects the less significant volumes of fertilizing inflows. General Creek has been used in our work as a control (Goldman, Moshiri, and Amezaga 1972) and the stream influence disappears within a short distance from shore. The transect at Cave Rock, along the sparsely settled east shore, shows very little variation in fertility with depth. The steady rise in productivity per unit of surface area simply reflects the steady increase in the photic zone with increasing depth offshore.

Discussion

The littoral zone of Lake Tahoe is characterized by narrow extent and a relatively small contribution to the overall algal productivity of the lake. Still, it remains the most visible feature of the lake to the largely landbound population and presented the first visible evidence that eutrophication was occurring in the inshore areas. Further, the food chain contribution of the littoral zones of deep lakes like Tahoe and Baikal in the USSR may be much greater than these measures indicate. The luxuriant growths of periphyton may reflect a restriction of nutrient-enriched waters to the shallow zone of Lake Tahoe by a thermal bar. The periphyton seem particularly sensitive to the spring inflow of nutrients, warming temperature, and increasing photoperiods. The most luxuriant growths of attached algae are usually to be found in the vicinity of stream mouths, but most of the lake's inshore areas are visibly green in spring and early summer. Occasionally, large mats of decaying periphyton and associated bacteria break off and float to the surface or are carried in from streams. Their decay is suspect of triggering a secondary bloom of phytoplankton such as the large lens of Scenedesmus that is usually observed near the mouth of the Upper Truckee River in spring.

The diversity of the periphyton is similar throughout the year, although the species making up the summer and winter populations are quite different. The lower diversity occurring to the east of the Upper Truckee River mouth is accompanied by a high phytoplankton production. If one accepts the theory that more eutrophic situations are less diverse, this is a logical expectation.

The Upper Truckee River sediment plume extends well along the southeast corner of the lake and appears to reduce periphyton growth through shading or be dissipated and deflected east before it can fertilize the southern stations. It does, however, greatly influence the phytoplankton and planktonic bacteria which thrive in the vicinity of the plume (Goldman et al. 1973, 1974).

Because glass substrata are utilized, it seems likely that our estimates of periphyton growth somewhat underestimate natural growth. An irregular substrate provides not only easier attachment, but a variable protection for periphyton growth. The heavy mats that break loose from the wave zone following a spring storm are never duplicated on our slides. Further, we have no real estimate of grazing by the variety of organisms that utilize periphyton as food.

Although aquatic insect larvae and protozoans may graze the periphyton community in Lake Tahoe, the California crayfish Pacifastacus leniusculus is probably the most important benthic organism in Lake Tahoe (see Section XI). Studies have shown a distribution of the P. leniusculus population between 0 and 60 m depth in Lake Tahoe with maximum densities occurring between 10 and 20 m (Abrahamsson and Goldman 1970). This area of concentration is exclusively in the littoral zone of the lake and may, because of its great abundance, have considerable influence on the ecology of the littoral zone.

The shallow water environment of the littoral zone of even a deep lake such as Tahoe is of great interest to the limnologist. Although the water may remain relatively clear, it contains higher levels of nutrients than the pelagic waters and has much greater contact with the substrata. The organisms which frequent this zone have the first opportunity to concentrate the nutrients into organic matter. This tends to reduce the amount immediately available for a spring phytoplankton bloom and in a sense buffers the system against loss of transparency. A better understanding of stream and littoral zone periphyton productivity should help to improve our understanding of the dynamics of shallow and deep lakes alike.

SECTION X

ZOOPLANKTON

Introduction

Historically zooplankton of Lake Tahoe have received relatively little study and it was not until the early part of this century that any significant interest was shown in the invertebrate fauna. Pioneer studies by Ward (1904); Juday (1907); and Kemmerer, Bovard, and Boorman (1923) were of a general survey nature. More recently a comprehensive list of many invertebrate groups including zooplankton has been published by Frantz and Cordone (1966) and Richerson (1969). Richerson, Armstrong, and Goldman (1970) have completed the first intensive documentation of zooplankton dynamics and community ecology.

The major objectives of the study reported here were to quantify seasonal changes in abundance of pelagic zooplankton and relate these changes to other limnological variations such as primary productivity, the wax and wane of phytoplankton populations, and intra-specific interactions among the zooplankton themselves.

About 25 species of free-living crustaceans and 14 species of rotifers that have been identified compose the known zooplankton community of Lake Tahoe (Table 34). Many of these animals were identified through the efforts of previously mentioned investigators who sampled a broad spectrum of the Tahoe environment. Our study concentrated sampling at deep water pelagic stations (greater than 120 m) and did not normally encounter the many benthic or littoral zone forms.

Three cladocerans were taken routinely. *Daphnia rosea*, *D. pulex* (*pulicaria* of some taxonomists), and *Bosmina longirostris* were common. Infrequently, *Chydrous* sp. was collected. Copepods taken consistently included *Epischura nevadensis*, *Diaptomus tyrrelli*, and an occasional cyclopoid. Apparently a new addition not reported from sampling by earlier investigators is the harpacticoid copepod *Bryocamptus zschokkei*. It was rare, but occurred in three samples in both 1970 and 1971. Another rare crustacean in the pelagic collections was a member of the order Ostracoda which was found on two occasions in the fall of 1970.

It should be noted that since the end of the current study, another crustacean *Mysis relicta*, the opossum shrimp, has begun to appear sporadically in samples and undoubtedly has become established as a major zooplankter in Lake Tahoe since its introduction in 1963 (Linn and Frantz 1965). Collections of *Mysis* by presently used methods are not representative of its true numbers because of its particular behavior and swimming characteristics (net avoidance, strong diurnal migration through considerable depths, large size, etc.).

The list of rotifers in Table 34 appears to be the most recent and complete compilation of rotifers occurring in Lake Tahoe. Frantz and Cordone (1966) did not include them. The concurrent study by Richerson (1969) compiled a list which has been lengthened and revised. Eleven genera and species and three unidentified forms are now known. Some rotifer determinations were made by W. T. Edmondson (personal communication).

Table 34. Lake Tahoe zooplankton

A list of pelagic and benthic invertebrates composing the zooplankton community of Lake Tahoe compiled from the work of Frantz and Cordone (1966), Richerson (1969), and the Tahoe Research Group studies. An asterisk (*) indicates presence in the 150 to 0 m vertical tows. Code words for comments are: C=common, R=rare, P=pelagic, B=benthic, V=very.

Phylum: *Rotifera*		
Class: *Monogononta*		
Order: *Ploima*		
Family: *Brachionidae*		
Epiphanes ? (Rotifer I)	*	C,P
Kellicottia longispina	*	VC,P
Keratella cochlearis	*	VR,P
Keratella quadrata	*	R,P
Monostyla sp.	*	VR,P
Notholca (*striata* type)	*	R,P
Notholca (*squamula* type)	*	C,P
Family: *Gastropidae*		
Ascomorpha (*agilis americana* type)	*	VC,P
Chromogaster ovalis	*	VC,P
Family: *Lecanidae*		
Lecane sp.	*	VR,P
Family: *Synchaetidae*		
Polyarthra sp.	*	C,P
Family: *Trichocercidae*		
Trichocerca sp.	*	VR,P
Unidentified Rotifer I	*	C,P
Unidentified Rotifer II	*	C,P
Phylum: *Arthropoda*		
Class: *Crustacea*		
Subclass: *Entomostraca*		
Order: *Copepoda*		
Suborder: *Calanoida*		
Family: *Temoridae*		
Epischura nevadensis Lilljeborg	*	VC,P
Family: *Diaptomidae*		
Diaptomus tyrrelli Poppe	*	VC,P

Table 34 (cont'd)

Suborder: *Cyclopoida*		
Family: *Cyclopidae*		
Cyclops vernalis Fischer	*?	VR,B
Macrocyclops albidus Jurine	*?	VR,B
Suborder: *Harpacticoida*		
Family: *Canthocamptidae*		
Bryocamptus zschokkei	*	VR,B
Order: *Cladocera*		
Family: *Sididae*		
Latona setifera O. F. Muller		R,B
Family: *Daphnidae*		
Daphnia rosea Sars	*	C,P
Daphnia pulex (pulicaria) Richard	*	C,P
Simocephalus serrulatus Koch		R,B
Family: *Bosminidae*		
Bosmina longirostris O. F. Muller	*	C,P
Family: *Macrothricidae*		
Drepanothrix dentata Euren.		R,B
Ilyocryptus acutifrons Sars		R,B
Eurycercus lamellatus O. F. Muller		C,B
Camptocercus rectirostris Schodler		R,B
Acroperus harpae Baird		R,B
Alona affinis Leydig		C,B
Alona quadrangularis O. F. Muller		R,B
Pleuroxus denticulatus Birge		R,B
Chydorus latus Sars	*?	R,B
Chydorus sphaericus O. F. Muller	*?	R,B
Order: *Ostracoda*		
Family: *Cypridae*		
Candona sp.	*?	VR,B
Order: *Amphipoda*		
Family: *Talitridae*		
Hyallela azteca Saussure		R,B
Hyallela inermis S. I. Smith		
Family: *Gammaridae*		
Stygobromus hubbsi Shoemaker		C,B
Subclass: *Malacostraca*		
Order: *Mysidacea*		
Family: *Mysidae*		
Mysis relicta Loven	*	Common, but not in tow, P

Methods

Index station collections were made with a Clarke-Bumpus plankton sampler with a 12.5 cm mouth, flow meter, and a No. 20 (80 μ mesh opening) net. Triplicate vertical tows from 150 m to the surface were taken usually between 1030 and 1100 at a tow rate of about 50 m/minute. Samples were rinsed from the cod-end bucket into jars and preserved in 5% formalin. Flow meter readings taken before and after the tow allowed an estimate of the water volume filtered. This volume was about 1.2 m^3 per tow. Periodic flow meter calibration was done according to the manufacturer's recommendations (G. M. Mfg. and Equip. Corp., New York, N.Y.).

The entire sample, including rotifers, was counted under a dissecting microscope at medium magnification (30X or 45X) after the sample supernatant was drawn off and the remaining 5-10 mls was allowed to settle in a gridded Petri dish. Texts and references for identification included Ahlstrom (1940, 1943), Beachamp (1932), Donner (1966), Edmundson (1959), Gurney (1931, 1933), Humes (1955), Kincaid (1953), Marsh (1933), Pennak (1953), and Voigt (1957). Cladocerans and copepods were enumerated by life stages and identified to species when possible. Rotifers were identified at least to genus. Counts from the three tows were averaged after adjusting numbers according to the volume filtered. The data is shown in Figures 62 to 65 as number of individuals per cubic meter. A Burroughs 6700 computer together with a Calcomp Digital Incremental Plotter Model 563 were used for graphing Figures 62 to 65.

Results

Rotifers -

Rotifers are a numerically important part of the Lake Tahoe zooplankton. Populations of the four major genera, with a few exceptions, did not show significant upward or downward trends during the study period, but they were subject to large fluctuations in numbers from one sampling to the next. Conversion to biomass will eventually provide an important analysis of their importance relative to larger forms of the zooplankton (Figure 62).

Chromogaster ovalis, a small rotifer characteristic of unproductive waters was very common and numerous throughout much of the year. Peak populations of about $200 \cdot m^{-3}$ usually occurred in early winter and it was abundant from late fall through the end of winter. It became rare or nonexistent from June to October.

Ascormorpha (agilis americana type), a small raptorial rotifer, was common ($300\text{-}7000 \cdot m^{-3}$) throughout 1967-69 except for a brief decline in the fall of each year. In 1970 and 1971 the mid-summer decline occurred, but the numbers remained low for the rest of the year. There has also been a noticeable downward trend in total numbers each consecutive year since 1968.

Notholca (squamula type) population growth curves are variable in shape from year to year with no consistent temporal pattern. Peak numbers of about $2500 \cdot m^{-3}$ occurred in June of 1968 with lower peaks in June and August of 1969 and from February to May in 1970 and 1971. Hutchinson (1967) indicates that this is a cold water form.

Based on our sampling, Kellicottia longispina is the most dominant pelagic rotifer in Lake Tahoe. It suffered population crashes in 1969, but these did not recur in the next two years. Peak numbers (over $6000 \cdot m^{-3}$ in 1968) were reached in June most years and usually persisted until early winter. The population was seldom less than $10\text{-}50 \cdot m^{-3}$. These sedimentary feeders eat 10-12 μ size particles and are recognized as preferring the pelagic zone (Hutchinson 1967).

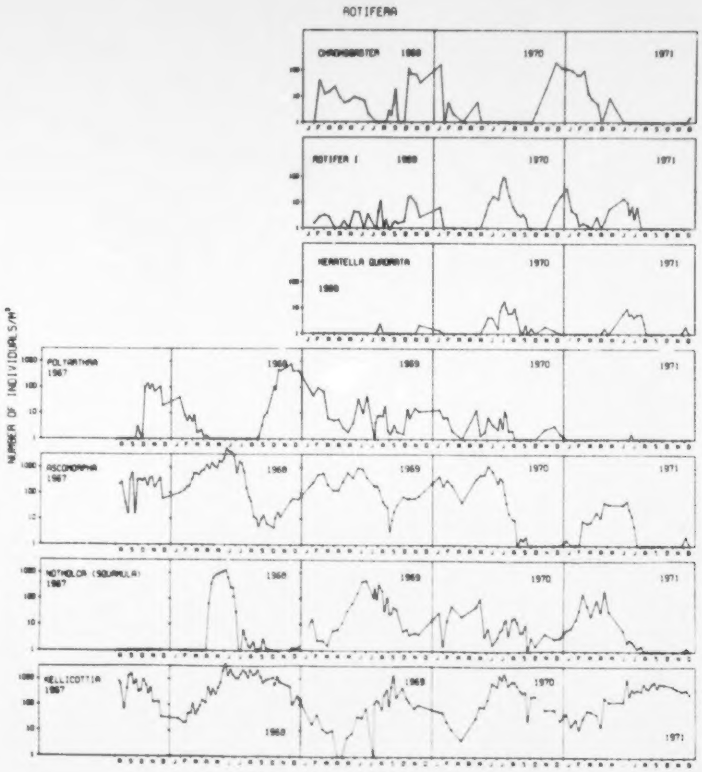


Figure 62. Numbers of individual rotifer species in a 150 to 0 m vertical tow at the index station of Lake Tahoe from mid-1967 through 1971.

Keratella quadrata, Polyarthra sp. and an unidentified rotifer also periodically made significant contributions to the rotifer population. Keratella, a strongly cyclomorphic pelagic form, tends to peak in abundance in mid-summer, die back in the fall, and exhibit a secondary peak in early winter. The 1971 data indicates Polyarthra may be undergoing a decline in Lake Tahoe. Maximum concentration of about $1000 \cdot m^{-3}$ occurred in the early winter of 1968. A mid-summer increase in 1969 and 1970 was bracketed by lower numbers in spring and fall. However, in 1971 Polyarthra appeared only briefly in July. The unidentified Rotifer I (Epiphanes?) has remained at low and fluctuating population levels throughout the study and appears to have both summer and winter peaks in abundance.

The other rotifers found and listed in Table 34 are as yet unidentified so that quantitative evaluation of their role in the Tahoe plankton community is not practical.

Copepods -

Although not extremely rich in number of species, the Lake Tahoe copepod community constitutes the major zooplankton component. Counts of adults, copepodites, and nauplii of the two major copepods Diaptomus tyrelli and Epischura nevadnesis revealed that they were by far the most abundant zooplankton. Both forms appeared to be slightly increasing in number with Diaptomus increasing most rapidly (Figure 63).

Epischura adult population levels were found to be about the same throughout the study period. Maximum density was near $200 \cdot m^{-3}$ and this peak was usually reached some time in mid or late summer. Rapid population decline occurred in the fall and a low number of adults persisted through the winter until the population increased, sometimes dramatically, in April or May. The copepodites followed a similar pattern. Density in 1971 was near $1000 \cdot m^{-3}$ at its peak. Nauplii were

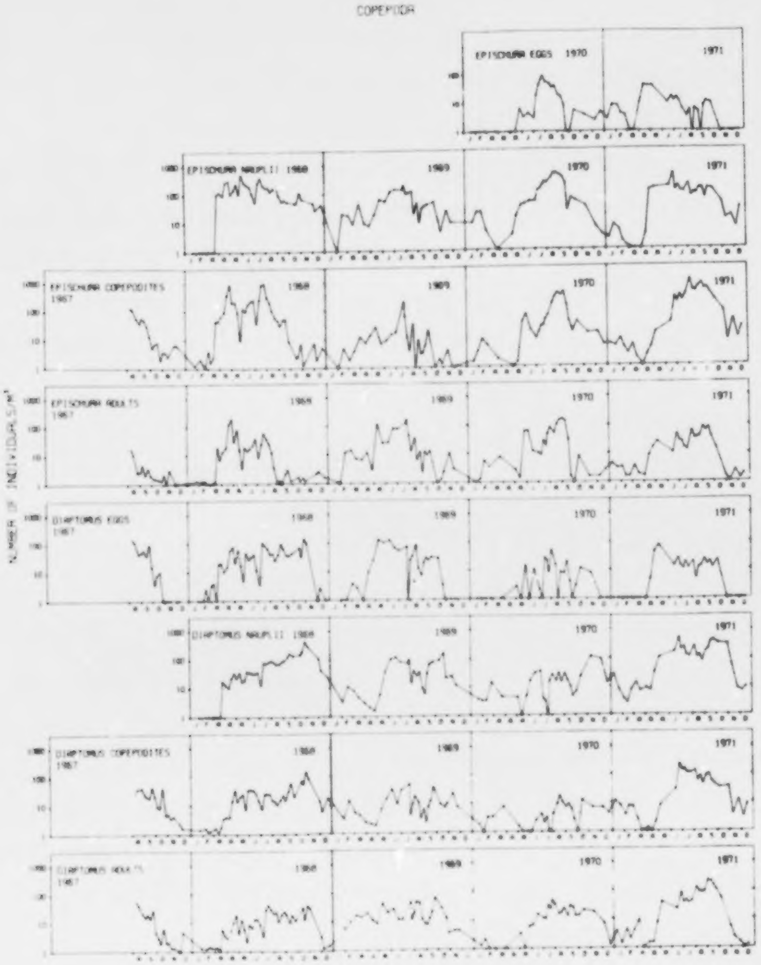


Figure 63. Numbers of individual copepod species in a 150 to 0 m vertical tow at the index station of Lake Tahoe from mid-1967 through 1971.

present in maximum numbers from May to August and exhibited a short-lived die-off in late winter. Eggs were most abundant in spring and summer when they reached concentrations of about $100 \cdot m^{-3}$.

Diaptomus numbers appeared to be increasing in all three life stages during the study period, but the egg number was found to be slightly less. All three forms followed similar yearly patterns with lowest numbers occurring in the late winter when less than $10 \cdot m^{-3}$ were found. Peak numbers occurred from May to October ($100\text{-}500 \cdot m^{-3}$). The numbers counted in 1970 were fairly low, but were followed by an obvious increase in 1971.

Cladocerans -

Perhaps the most striking phenomenon occurring in the Tahoe zooplankton during the study period was the almost complete disappearance of the cladoceran population. Both Daphnia and Bosmina began to decline significantly in 1970 and were absent from all index station counts by mid-1971 (Figure 64).

Bosmina adults were relatively abundant from 1967 to 1969 with a characteristic peak in abundance of $400\text{-}1000 \cdot m^{-3}$ occurring each fall. Bosmina embryos and adults remained at low densities of less than $10 \cdot m^{-3}$ in 1969 until late summer. Embryos peaked in abundance at about $50 \cdot m^{-3}$, but adults increased by nearly one hundred-fold in September. A steady decline of both life stages followed. In 1970, embryos made only sporadic appearances in winter and fall and adults occurred at low levels throughout the year with no fall increase. In 1971, no embryos were detected and adults gradually disappeared by June.

Daphnia followed a similar pattern of disappearance. Both embryos and adults maintained fairly uniform numbers throughout most of 1967-69, ranging from about 5 to $700 \cdot m^{-3}$. That density level continued to May

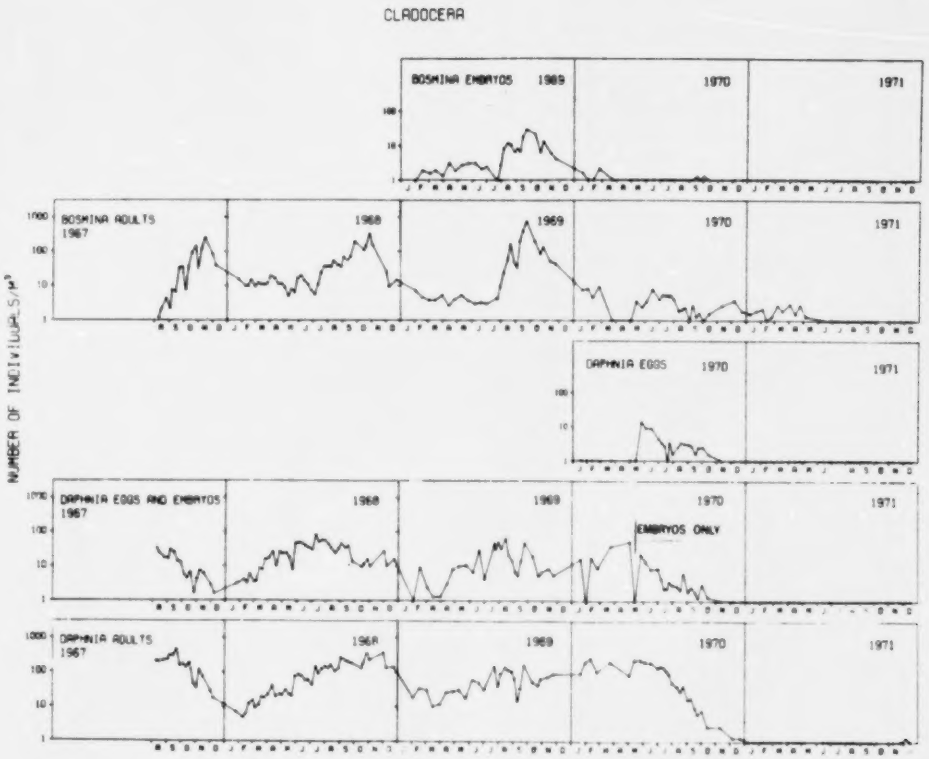


Figure 64. Numbers of individual cladoceran species in a 150 to 0 m vertical tow at the index station of Lake Tahoe from mid-1967 through 1971.

1970 and then a slow, steady decline continued to the end of the year. Daphnia eggs which had not been counted separately until May of 1970 showed a similar rate of decline. Only one Daphnia adult was counted in December of 1971!

As with rotifers, no attempt has been made to quantitatively evaluate the significance of the other copepods, cladocerans and malacostracans, and oscracods found infrequently in the samples.

Discussion

The Lake Tahoe zooplankton community appears to be undergoing a significant change. Species dominance appears to be shifting, but it is not yet clear whether or not total numbers of zooplankton are increasing. The lake formerly contained a large pelagic cladoceran population consisting mostly of Daphnia species and Bosmina longirostris. The data of Figure 64 indicate that not only have cladocerans almost entirely disappeared from the sampling area, but a progressive shift in time of zooplankton peak abundance has taken place (Figure 65). Such an occurrence is not unknown and it has been attributed to different causes. Predation by planktivorous fish (Anderson 1972, Brooks and Dodson 1965, Galbraith 1967, Hrbacek et al. 1961, Hutchinson 1971, Reif and Tappa 1966, Reimers 1958, Wells 1970, Wong and Ward 1972) has often been offered as an explanation for the disappearance of large cladocerans. Interspecific competition for available food (Brooks and Dodson 1965, Dodson 1970, Anderson 1970) or a change in the quality of the food supply caused by increasing euthrophication have also been mentioned (Bradshaw 1964, Beeton 1965, Brooks 1969, Zyblut 1970).

It is not yet clear what has led to the reduction of these large and important zooplankters, but it is suspected that successful introductions of both a large omnivorous zooplankter Mysis relicta and the

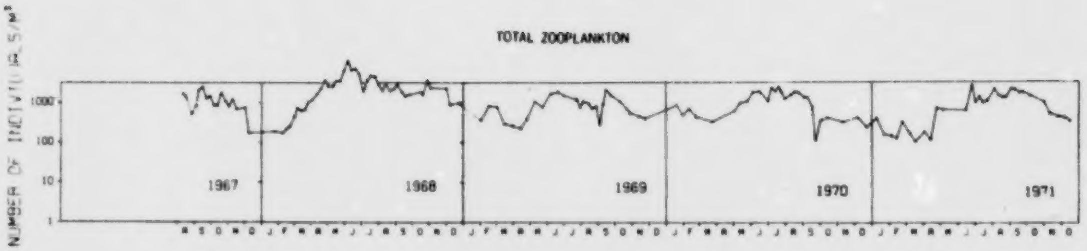


Figure 65. Total number of zooplankton in a 150 to 0 m vertical tow at the index station of Lake Tahoe from mid-1967 through 1971.

planktivorous kokanee salmon Oncorhynchus nerka have been major factors in the zooplankton species shift. Accumulation of population data on both fish and Mysis should resolve the questions developed in this report. The opossum shrimp Mysis relicta was introduced in 1963 to provide forage for the Tahoe trout fishery (Linn and Frantz 1965). It has been successfully introduced into other lakes (Furst 1965; Schumacker 1966; Sparrow, Larkin, and Rutherglen 1964) and has caused changes in zooplankton composition in some cases (Northcote 1972). Recent studies by Lasenby and Langford (1972, 1973) have indicated that adult Mysis can be voracious predators on Daphnia pulex, Bosmina, and the rotifer Kellicottia. They found that Mysis played a dual role in the ecosystem of Stony Lake, Ontario as a benthic detritivore by day which ascended by night to feed on Daphnia and Bosmina. There was even some evidence suggesting that Mysis were selective for the cladocerans, because there was a striking lack of diatoms and rotifers in the opossum shrimps' stomachs.

Mysis are known to be concentrated around the thermocline by night and descend to the near bottom when light intensity becomes too high in daylight (Larkin 1948; Mundie 1959; Beeton 1959, 1960; Wells 1960). Although occasionally present in shallow waters, they were more commonly found in deeper water where light from the surface does not produce a negative phototactic reaction (Robertson, Powers, and Anderson 1968). This diurnal cycle could occur year-round since temperature does not appear to be as much of a barrier to their vertical movements as it was once believed (Smith 1970). Juday and Birge (1927) observed them to tolerate temperatures ranging from 0° to 21°C in the surface waters of Trout Lake, Wisconsin. They have been kept in the Tahoe laboratory for nearly a month at room temperature (15°C) with no special precautions other than aeration. Daily short-term "high" temperature exposures in the epilimnion do not appear to affect their ability to feed there at night. It is entirely feasible that Mysis is at least partially responsible for the cladoceran disappearance, since their nocturnal ascent brings them into the area of the thermocline occupied by the pelagic cladocerans.

The unintentional introduction of the planktivorous kokanee salmon into Lake Tahoe in 1944 was followed by a series of kokanee fry plantings from 1949 to 1955 and from 1964 to 1969. This established the kokanee as an important member of the Tahoe fishery in the late 1960's (Cordone et al. 1971). These investigators determined that all sizes of kokanee are highly dependent upon zooplankton for food and observed that cladocerans and primarily Daphnia were found in 90 to 100% of the fish stomachs. Copepods, of which Epischura nevadensis composed the largest percentage, were present about 15% of the time.

The composition of kokanee food appears to be shifting away from an almost strictly cladoceran diet to one composed of several types of zooplankton. In 1963 and 1964, cladocera occurred in fish stomachs about 93% of the time, copepods 20%, and midge larvae 2%. In 1972, percent frequency of occurrence was 10% cladocerans, 53% copepods, 44% midge larvae, and 16% mysids (T. Frantz personal communication). Kokanee are facultative planktivores which will normally feed on the larger daphnids when they are present, but will take other smaller food sources when their preferred one diminishes (Brooks 1969). Their order of food preference is usually cladocerans, cyclopoids, and then calanoid copepods.

The interaction of the two nearly simultaneous species introductions into the Lake Tahoe ecosystem at different trophic levels may produce a series of complex changes with ramifications throughout the food chain. The changes in specific zooplankton abundance along with the increasing chemical enrichment might conceivably influence the rate of eutrophication of Lake Tahoe by altering the grazing pressure on phytoplankton.

Heavy predation usually has the effect of eliminating first the large forms such as Daphnia which allow smaller forms such as Bosmina to become dominant (Brooks and Dodson 1965, Hutchinson 1971). Apparently predation by Mysis and kokanee salmon has nearly eliminated both Daphnia and Bosmina, although other limnological factors may also be important. This is contrary to changes which usually occur when lake planktivores are selective of large size prey (Brooks 1968).

The removal of cladocera may bring about a shift in rotifers, although no significant change has been noted to date. Rotifers in Tahoe do not appear to have increased dramatically and some have even decreased (Figure 62). The large total number of zooplankton observed in 1968 was mainly due to the predominance of the rotifers Kellicottia, Ascomorpha, and Notholca (Figures 65, 66). The reason for this sudden growth and decline is not understood. There is a slight increase in copepods in 1970-71, possibly indicating that they are gaining a competitive edge over the rotifers. This change may continue until balance is restored between these two groups which filter feed on similar size particles (Brooks 1968). Polyarthra, Ascomorpha, and Chromogaster seem to be losing their place as dominant rotifers to Kellicottia populations.

The loss of the larger zooplankton which are more efficient filterers of a wider size range of algae and particles (Burns 1968) could also lead to a shift in phytoplankton dominance. Although it has not been demonstrated in a large lake, Hrbacek (1962) has shown that a population of Daphnia in fish ponds maintained water of greater transparency by being more efficient at the removal of large and small phytoplankton than a population of smaller herbivores which did not filter as rapidly or remove the larger "net" phytoplankton (>50μ). The implication of this is obvious for Lake Tahoe. Reduced water clarity even in pelagic waters is a strong possibility, because adequate numbers of large zooplankton no longer exist to remove large phytoplankton.

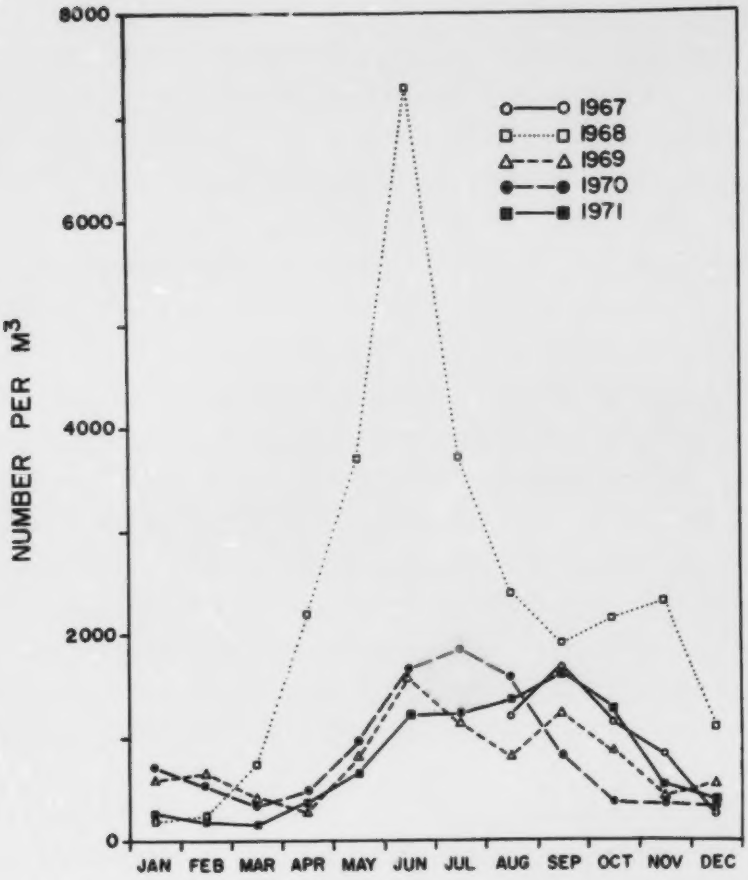


Figure 66. Seasonal number of zooplankton at the index station of Lake Tahoe from mid-1967 through 1971. Each point is the average for the month.

Removal of the most efficient phytoplankton grazers may also change the diversity and stability of the Tahoe phytoplankton and might well cause an increase in both large and small forms. Richerson (1969) believes that the "grazing pressure" on Lake Tahoe phytoplankton was greatest during late summer and fall particularly because of the presence of Daphnia. He indicated that a high rate of phytoplankton turnover existed at this time which supported a diverse zooplankton population. It should be noted that these observations occurred before the reduction in cladocerans. Brooks (1969) believes that "a shift in dominance from large-bodied to small-bodied planktonic herbivores (as a result of size-dependent predation) should cause a lake to become more eutrophic." Margalef (1968) has theorized that eutrophic lakes tend to exhibit less diversity and stability in their plankton assemblages. Therefore, a loss in zooplankton diversity in Tahoe might well cause certain large algal forms to become more dominant.

Because of the introduction of Mysis, two important changes in the food availability may occur for the Tahoe fishery.

1) Mysis are providing a heretofore unavailable food source to bottom feeding lake trout (Salvelinus namaycush) which are known to feed on them when available (Rawson 1961).
2) If Mysis are predatory in Tahoe, they are removing the major food source (cladocerans) for kokanee salmon (Oncorhynchus nerka) while remaining fairly unavailable themselves as a pelagic food source because of their diurnal, vertical movements to and from the photic zone where kokanee normally feed.

The increasing occurrence of Mysis in lake trout stomachs is now substantiated. In 1970 none of the trout checked contained mysids (Frantz and Cordone 1970), but in 1971 the frequency of mysids jumped dramatically to 60% (T. Frantz personal communication). This should lead to an increase in the number of lake trout in the fishery. They depend heavily on cladocerans and copepods when young and they are a strongly piscivorous fish after attaining a length of 0.5 m. This predatory nature may lead to the reduction in other game (white fish, rainbow trout) and non-game fish (sculpins, minnows, suckers) in Lake Tahoe. It is also possible that predation on crayfish, probably the most important benthic detritivore, may become more severe.

If the second change in food availability occurs (it appears that cladocerans are very rare now), then one is tempted to predict that kokanee salmon numbers will decline from a lack of an adequate prime food source. It is still a question whether they can succeed as facultative planktivores feeding largely on pelagic zooplankton, but it has occurred before (Northcote 1972).

It is interesting to note that as of September 1973, cladocerans were not completely gone from Lake Tahoe because they were collected in Emerald Bay. Daphnia may exist there because of reduced predation by kokanee. The fish may not frequent the bay due to its shallow nature or Daphnia may be less susceptible to predation because of the lower transparency of the water there. Mysis may also find conditions less ideal than the main lake because of the relative shallowness (63 m) of the bay. There is also the possibility that they do not exist there because the very shallow (2.5 m) mouth may have acted as a barrier to their horizontal migration. It is not known if Mysis are present in Emerald Bay, although they were released there during the original introduction in 1963-64 (Linn and Frantz 1965).

One of the most significant indications of change in zooplankton standing crop in Lake Tahoe is the progressive shift in the peak zooplankton abundance. Not only has the peak occurred at a later date each year since 1968, but the curve has changed from bimodal to unimodal (Figure 66). This change in curve configuration is apparently due to the disappearance of cladocerans which were most numerous in the fall. This is significant especially in view of the primary productivity information presented in Section VI that peak primary productivity is occurring later each year. If _Bosmina_ and _Daphnia_ depend on specific algal and/or bacterial conditions for growth, the temporal shift in primary productivity may delay development of populations until other environmental conditions are unfavorable. If the phytoplankton peaks are very close to the end of the main algal growing period at Tahoe (just before light and temperatures begin to decline), it is entirely possible that the physical and biotic environment are limiting the growth of the cladoceran population. It is suggested that this shift in production (both primary and secondary) may be as important as kokanee or _Mysis_ predation in elimination of the cladocerans, but little evidence is available.

It appears that Lake Tahoe is losing some diversity in zooplankton species. The large phytoplankton, without grazing pressure, may gain a competitive interspecific advantage over smaller cells which are utilized by smaller zooplankton. This could conceivably reduce the diversity of phytoplankton species in the lake and water clarity. A similar process would be true for zooplankton. With competition for food lessened together with an increase in fish predation on the remaining smaller sized zooplankton community, Lake Tahoe may support fewer dominant species, but greater numbers of those with a particular feeding advantage.

SECTION XI

BENTHIC ORGANISMS

CRAYFISH

Introduction

The California crayfish Pacifastacus leniusculus is probably the most important benthic organism in Lake Tahoe and has achieved considerable international importance as an introduced species in European waters. It is believed that the first introduction of P. leniusculus into Lake Tahoe took place in 1895 when 19 males and 37 females from the Klamath River were introduced into the Truckee River in the vicinity of Reno. In 1909 more crayfish were introduced "with the object of providing food for the introduced varieties of fish as well as a table delicacy for our citizens..." (La Rivers 1962). Three hundred and sixty crayfish, probably from coast streams in Oregon, were placed in the Truckee River, the Carson River, and Washoe Lake. A third introduction in the water systems of Lake Tahoe was made in 1916.

From this information it may be concluded that there were no endemic crayfish in Lake Tahoe. This theory is further supported by reports of the diet of the Washoe Indians who lived around the lake during the summer (Downs 1966). Though they were clever fishermen and had no taboos on food, there is no indication that they either ate or used crayfish as bait which they should have if these animals were native to Lake Tahoe.

The various introductions of P. leniusculus to Lake Tahoe included crayfish from several different water systems. It is likely that the lake received several subspecies including P. trowbridgii (Stimpson), and P. klamathensis (Stimpson). This resulted in hybridization, and intergrade forms of the subspecies of P. leniusculus are now found in Lake Tahoe.

The P. leniusculus in Lake Tahoe show a variety of color phases from greenish-brown through blue and red. The majority are greenish-brown, and it is not known whether the variability is genotypic or phenotypic.

Trapping studies of the distribution of the P. leniusculus population between 0 and 60 m depth (where 97.2% of the population resides) in Lake Tahoe indicates that their maximum densities occur between 10 and 20 m (Fig. 67). The lower density of crayfish at 0-10 m depth is probably due to the high light intensity, as well as the scarcity of food materials caused by heavy wave action in the shallower areas of the lake. High light intensity has been shown to inhibit primary production in the upper water levels at high altitudes (Goldman 1963) and at high latitudes (Goldman, Mason, and Wood 1963). Periphyton production may be somewhat reduced in shallow waters from a combination of high light intensity and wave action. Strong wave action, particularly during cold weather, has also been observed to cause appreciable mortality of crayfish in shallow areas of the lake. This may result directly by physical injury of rolling rocks on the bottom, displacement, and perhaps indirectly by reduction of its food supplies. Below the depth of 40 m the crayfish population declines very rapidly, even if the bottom substrate is very suitable for crayfish at this depth. A reason for the rapid decline of the population below 40 m depth seems to be the inability of the crayfish eggs to hatch in the cold water found below this depth during the summer months.

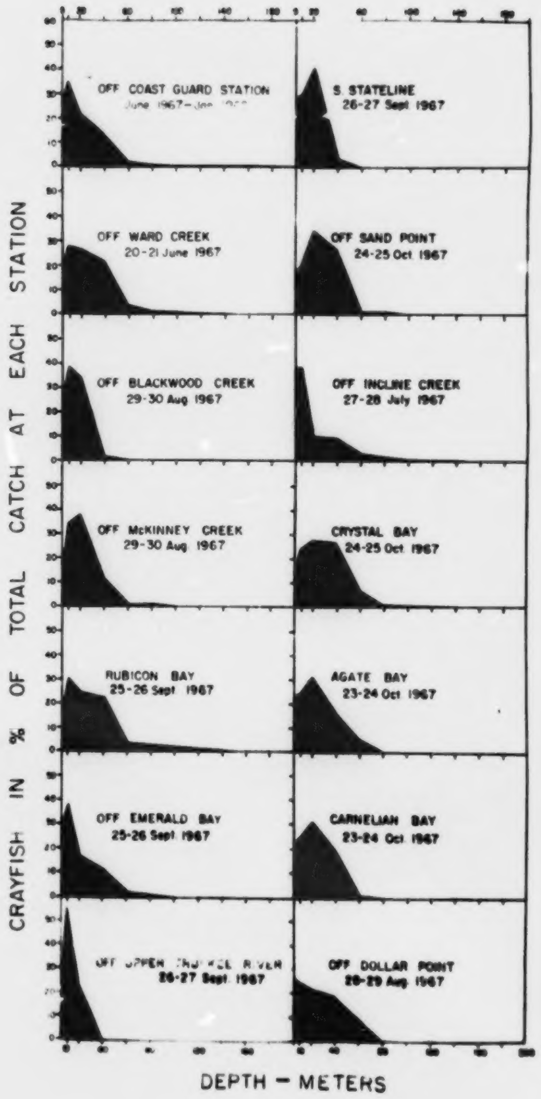


Figure 67. Depth-distribution of the crayfish population at various locations in Lake Tahoe in 1967.

Methods and Results

Utilizing population data obtained by SCUBA and trapping methods, the crayfish population in Lake Tahoe during 1967 at depths from 0-40 m (which includes 90% of the population) was estimated to include 55.5 million individuals. Based on an average weight of 20 grams per animal, the standing crop of adult crayfish in this depth range was calculated to be about 1,100,000 kg (Abrahamsson and Goldman 1970). Studies of crayfish from different areas of Lake Tahoe have shown that there is a large variation in the average body length of these animals. The area off the Coast Guard Station has a very stony bottom which provides good cover against predation which results in high density, a shortage of food, and a stunted crayfish population. The average body length was found to be inversely related to the population density and is therefore greater in deep water (Abrahamsson and Goldman 1970). Furthermore, there are local sources of pollution in Lake Tahoe which may lead to higher levels of productivity in certain areas (Goldman and Carter 1965). There are also substrate differences which may have important effects on the total population structure. The bottom material in Crystal Bay, for example, consists of large stones scattered over a plain sediment bottom, which has been receiving quantities of silt from building activities on the Incline Creek drainage. This substrate provides little protection for the crayfish population and leads to a high predation level, low density, abundance of food, and a greater average length per animal. All these factors correlate positively with the low population densities encountered in the deeper regions (Abrahamsson and Goldman 1970).

The percentage of mature crayfish within the total population increases with an increase in the size of the animals up to a point where 80-100% of the members of the population larger than 95 mm are sexually mature. This indicates that almost all adult individuals of both sexes take part in reproduction every year. This was not found for Pacifastacus by Miller (1960) nor for Astacus by Svärdson (1949).

Aquaria observations have shown that spawning may, to a great extent, be influenced by such factors as high population density, shortage of cover, and lack of nutrition. Pleopod egg counts show that there is a considerable variation in egg production, but there is a positive correlation between body length of females and the number of eggs produced. The average number of pleopod eggs of Lake Tahoe crayfish during 1967 was 110 eggs per female, based on a sample of 120 females (Abrahamsson and Goldman 1970).

As already indicated, the maximum density of the P. leniusculus population in Lake Tahoe occurs between 10 and 20 m. This area of concentration is exclusively in the littoral zone of the lake and Pacifastacus may, because of their great abundance, have considerable influence on the ecology of the littoral zone.

Studies on juvenile stages in a number of Decapoda indicate that these animals are strictly algal and detrital feeders (Blegvad 1914). Pacifastacus is an omnivore and in addition to consuming plant and animal food, ingests a variety of detritus and probably a number of benthic organisms including immature aquatic insects (Moshiri and Goldman 1969).

Immature periphyton communities in the littoral zone of Lake Tahoe display a high rate of productivity. As the community develops and the density of growth reaches a maximum, an equilibrium may exist before the winter decline. The mature periphyton community, without grazing, only produces new cells to replace old and dead cells. The productivity may therefore decrease in a climax or equilibrium state (see Section IX).

It seems likely that the aquatic periphyton community is similar to a terrestrial grassland community which maintains a higher productivity when they are grazed by herbivores. The presence of a crayfish population in the littoral zone of the lake may increase the productivity of periphyton by grazing pressure and may provide an efficient recycling of nutrients for both attached and free-floating communities which would otherwise be restricted to the periphyton community (Goldman and Amezaga 1974).

The possibility that the periphyton community is maintained in a more productive state by the grazing of the Lake Tahoe crayfish population seems consistent with the observations in the lake. The primary productivity of Lake Tahoe is very high off Tahoe City. The standing crop of crayfish is also most dense in this area of the lake which may reflect a combination of food supply and abundant cover (Abrahamsson and Goldman 1970).

At present very few crayfish are removed from Lake Tahoe except by predation. If harvested efficiently, crayfish might provide one means of permanent removal of organic matter from Lake Tahoe which is primarily valued for its present low productivity. Further study is needed to determine how great a sustained yield the lake could provide today. Its steadily increasing fertility will probably cause a higher production of crayfish in the future (Abrahamsson and Goldman 1970).

International Importance of Crayfish Research at Tahoe

The importance of the species *P. leniusculus* is not limited to its influence on the ecology of the littoral zone in Lake Tahoe. It has been introduced into Sweden to rejuvenate the crayfish fishing industry there since the indigenous Swedish crayfish population of *Astacus astacus* has been steadily decimated by the fungus *Aphanomyces astaci* first noted there in 1907. Since then, this "crayfish plague" has devastated about half the country's crayfish waters, with new areas being infected every year. This has caused severe economic consequences for the fishery and presently it is calculated that every year the fungus causes damage estimated at tens of millions of crowns in Sweden (Abrahamsson 1973).

In 1960 under the suggestion of the Swedish general consul in San Francisco, Erik von Essen, 100 Pacifastacus were introduced to an experimental lake outside Stockholm. These crayfish proved to be immune to the fungus and survived, grew, and reproduced satisfactorily. This motivated a more thorough ecological study of the species which was begun by Dr. Sture Abrahamsson in Sweden. In 1967 and 1968, Abrahamsson and Goldman (1970) studied Pacifastacus in its natural habitat at Lake Tahoe. A portion of the information obtained from this work has already been included in this report. The results of their studies indicated that P. leniusculus was a suitable species for a large scale introduction into Sweden. In 1969, under supervision of the Swedish Fisheries Board and the California Department of Fish and Game, about 60,000 adult crayfish were transferred from Tahoe to Sweden after first being held in quarantine.

Because of the risk of transferring parasites and fish diseases when importing adult crayfish, in subsequent years it was decided to stop importing adult crayfish and to continue the restoration program with Pacifastacus hatched in Sweden. This necessitated the development of hatching techniques in Sweden. This work was begun in Sweden under the direction of Dr. Abrahamsson with our continued cooperation. A high degree of success in developing hatching technology was reported by Dr. Abrahamsson just before his death following the First International Crayfish Symposium held in Hinterthal, Austria in 1972. The parasite and disease-free, hatched young continue to be released into lakes and streams and it is hoped that it will eventually raise the production levels of the Swedish crayfish industry to pre-plague levels. Pacifasticus leniusculus has the advantage of being more cold water tolerant than Astacus astacus and therefore can colonize more northern lakes. This example of international cooperation has been greatly appreciated in Sweden where crayfish assume great importance at summer parties throughout the land.

The initial work with P. leniusculus at Lake Tahoe and in Sweden has stimulated the initiation of aquaculture facilities for this species on the Davis campus under the direction of Drs. Goldman and Graham Gall. The experimental system is based on a water-recycling trout hatchery where nutrient-rich trout culture effluent will be used to grow macroscopic hydrophytes as a forage plant for the crayfish. This work is just beginning, but will extend and continue the work carried on during the period of EPA support.

SYNOPTIC SURVEY OF OTHER BENTHOS

Methods

Thirty-nine locations were chosen, evenly distributed over the lake on a grid, plus one station in Emerald Bay and one on the "lakemount". Sampling was conducted between 1 August and 26 October 1968 and served as the basis for a study of sedimentation in the lake (Court, Goldman, and Hyne 1972; see Section IV). Only one sample, using a Shipek sampler, was taken from each station so that a high degree of quantitative reliability cannot be claimed for the collections. The sediment samples collected varied in amount from less than one liter to more than four liters, depending on the substrate, and were washed and sieved before sorting. Lake water was used for the washing, and care was taken not to cause a grinding of the organisms in the washing of the sand and silt. Sieving was graded and fine enough to prevent the passage of even

Table 35. Organisms found in benthos samples from Lake Tahoe

Class	Genera	No. of stations organisms present	Total no. organisms		% of Total no. organisms
Protoza	Tetrameris	3	7		
				7	.8
Turbellaria	Phagocata	20	79		
	Dendrocoelopsis	1	3		
	Rhynchoscolex	1	1		
				83	9.3
Nemata	Trilobus	8	25		
	Dorylaimus	8	23		
	Iotonchus	8	20		
				68	7.6
Oligochaeta	Peloscolex	19	57		
	Lumbriculus	3	26		
	Limnodrilus	4	24		
	Henlea	2	19		
	Ilyiodrilus	5	13		
	Rhynchelmis	3	8		
	Haplotaxis	1	5		
	Naidium (Breviseta)	1	2		
	Eiseniella	1	2		
	Aeolosoma	1	1		
	(Immature)	3	19		
	(Newly hatched)	4	20		
	(Cocoons)	9	24		
	(Eggs)	2	2		
				222	24.9
Ostracoda	Candona	26	152		
				152	16.9
Copepoda	Diaptomis (Tyrelli)	1	37		
	Epishura	1	3		
				40	4.5

Table 35. Cont'd.

Malacostraca Amphipoda	*Stygobromus*	30	219		
	Hyalella	9	28		
	(Decomposed)	2	2		
	(Unidentified)	2	2		
				251	28.2
Insecta (Chironomidae)	*Orthocladiinae**	6	17		
	Procladius	2	2		
	Chironomus (*Atritibia*)	1	1		
	Phaenopsectra	1	1		
Insecta (Plecoptera)	*Capina*	3	7		
	(Terrestrial Gnat)	1	1		
	(Midge)	1	1		
	(Larva)	1	1		
	(Diptera adult)	1	1		
	(Unidentified)	1	1		
				33	3.7
Acari	*Lebertia*	2	2		
	Limnochares	1	1		
				3	.3
Mollusca Gastropoda	*Parapholyx*	1	6		
	Gyraulus	1	1		
				7	.8
Pelecypoda	*Pisidium*	2	4.4		.5
Terrestrial Arachnid	*Arachnida**	1	1		.1
Miscellaneous	Eggs	9	18		
	Cocoons	1	3		
				21	2.3
	Total No. of Organisms Found			892	

*Not identified to genus.

such small organisms as cladocerans and copepods. Following the washing, the samples were preserved in formalin in small vials. The various organisms were then identified and enumerated.

Results and Discussion

Thirty-three different genera representing a total of twelve different classes of animals were identified in the benthos samples (Table 35). Two genera composed 46.6% of all identified organisms. The dominant organism found in 30 of the 41 stations was Stygobromus (Amphipoda). A total of 219 of these were identified, which represented 27.5% of all the identified organisms and 24.5% of all organisms found. The second dominant organism found in 26 stations was Candona (Ostracoda). One hundred and fifty two were found which represented 19.1% of the identified organisms.

The total number of organisms found in any one sample varied from 0 to 79 (Fig. 68). Values of diversity per individual were computed for each station and varied from 0 to 2.94 bits per individual (Fig. 69). Values of diversity per individual for our data on benthos were probably more relevant than total number of individuals per sample, due to the limited number and difficulty of obtaining samples of comparable size.

The results of the benthic survey are difficult to interpret, for there does not appear to be a systematic pattern to either the distribution of numbers of organisms or the distribution of biotic diversity. This condition is especially evident when compared to the synoptic surveys of primary productivity where the primary productivity rate increased sharply near the mouths of some of the creeks (Goldman, Moshiri, and Amezaga 1972; and Section VII of the present report). It is quite possible that the lack of pattern in the benthos data may be a result of the lack of replicated samples and the small, variable sample sizes.

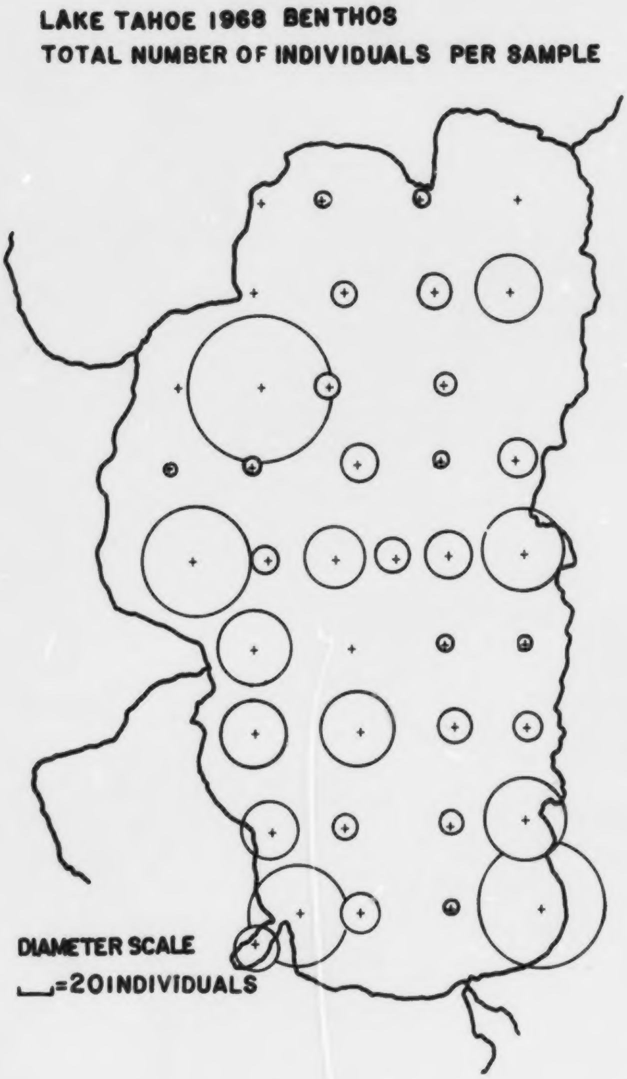

LAKE TAHOE 1968 BENTHOS
TOTAL NUMBER OF INDIVIDUALS PER SAMPLE
DIAMETER SCALE
=20 INDIVIDUALS

Figure 68. Number of organisms found in benthos samples at different stations in Lake Tahoe collected between 1 August and 26 October 1968.

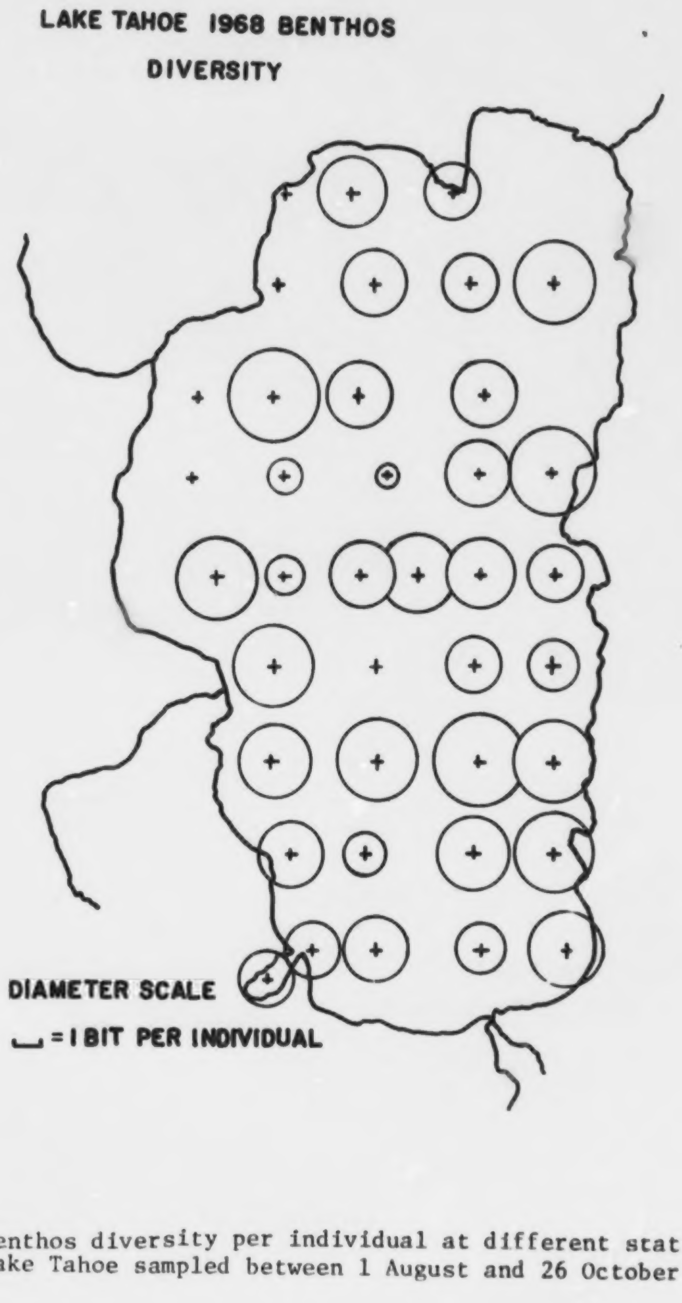

LAKE TAHOE 1968 BENTHOS
DIVERSITY
DIAMETER SCALE
= 1 BIT PER INDIVIDUAL

Figure 69. Benthos diversity per individual at different stations in Lake Tahoe sampled between 1 August and 26 October 1968.

However, the abundance and diversity of the benthic organisms may not be functions of the same environmental property as the abundance, productivity, and diversity of the phytoplankton. Algae are clearly associated with the mouths of creeks and their productivity has been shown to be stimulated by additions of creek water (Goldman and Armstrong 1969). The environmental factors that affect the benthos have not been determined, and a lack of pattern in benthic numbers and diversity may be an indication that nutrient enrichment is not a primary factor limiting the abundance of various species of benthos.

SECTION XII

EFFECTS OF MARINAS AND ECOLOGY OF A TAHOE BASIN STREAM

A LIMNOLOGICAL STUDY OF STAR HARBOR, A TAHOE MARINA

Introduction

The management of harbors and marinas has long been a problem for both the shipping industry and for recreation. In heavily used waterways there is increasing concern for navigation hazards, docking facilities, and general traffic control and safety measures. However, in a lake such as Tahoe, particular attention is directed towards water quality. Noting Tahoe's clear waters, the public is particularly concerned with the threat of eutrophication through increased use of the basin for recreation by a growing population. Sewage disposal systems have replaced most septic tanks and the bulk of the sewage is now being exported out of the basin, even after tertiary treatment. Stricter building codes are being enforced and many previously ignored questions concerning water quality are being faced by state agencies, local government, and land developers alike.

In the construction of on-shore developments, there is particular concern for excessive land disturbances. Road building and tree removal can cause severe erosion which releases nutrients and silt to the lake. Another problem which is peculiar to harbor developments is water stagnation. This allows nutrients flowing in from the streams to accumulate in the harbor and allows for the buildup of large populations of algae and sediment, which are eventually carried into the lake.

Star Harbor is a small land development, approximately 17 acres in size, on the north shore of Lake Tahoe, one mile east of Tahoe City, California (Fig. 1). Prior to construction, the area was a marsh at the mouth of Burton Creek, which has a 3100 acre watershed. Another small stream with a 900 acre watershed, which is primarily springfed, also empties into the development site. During years of excessive snowmelt, Burton Creek flooded into this marsh, carrying large amounts of debris and silt. In the first phase of construction of Star Harbor, an impoundment was built along the floodplain of the creek, creating a channel of quiet water at the mouth of the creek 2.5 m in depth, to be used as an anchorage for boats belonging to the residents living in the condominiums along the shore. The rest of the marsh was drained and a new creek was constructed from the spring flows. Part of the drainage was diverted along the east side of the property where it flows into one of the lagoons, while the major portion of the drainage was diverted along the west side of the property to form a new creek, Polaris Creek, which is now being used as a trout spawning channel because of its cold (12°C), swiftly moving water. Now both streams flow into the main channel. Between March 1970 and September 1971 a limnological study was conducted at Star Harbor as a M.S. thesis (Coil 1971). The purpose of this study was to determine: (1) if the development causes any biostimulatory effects on algal growth in the lagoon and future harbor, (2) what the level of nutrients is now entering the harbor from its tributary stream, (3) if the harbor has any effect on the near-shore waters of the lake, and (4) a possible water management strategy in order to minimize any eutrophication in the lagoon and harbor and reduce the flow of nutrients and sediment into the lake.

Methods

Seven sampling locations were chosen: one in each of the two streams which are tributary to the lagoon, four within the lagoon itself, and one in the lake (Fig. 70). The following parameters were measured on a monthly basis at each station:

- Water Chemistry
    - Nitrate
    - Phosphate
    - Iron
    - Inorganic carbon
- Phytoplankton (algae)
    - Numbers of individuals
    - Biomass (fresh weight)
- Primary Productivity (the growth rate of algae) -- utilizing the sensitive carbon-14 method of measuring photosynthesis (Goldman 1963).
- Physical Factors
    - Light
    - Temperature

Samples were collected at a 1-m depth at each station. Productivity samples were incubated in situ and all other analyses were performed at the limnology laboratory at Davis, California.

In addition to this regular sampling, biostimulation experiments were performed by the addition of both stream water and harbor water to samples of Lake Tahoe water. Different concentrations of water were added to the lake water to determine if there was any stimulation to algal growth by the addition of water from Star Harbor. These experiments give an indication of the consequences of mixing the now partially impounded lagoon waters with the lake.

Results

Results of nine samples collected between 14 April 1970 and 21 January

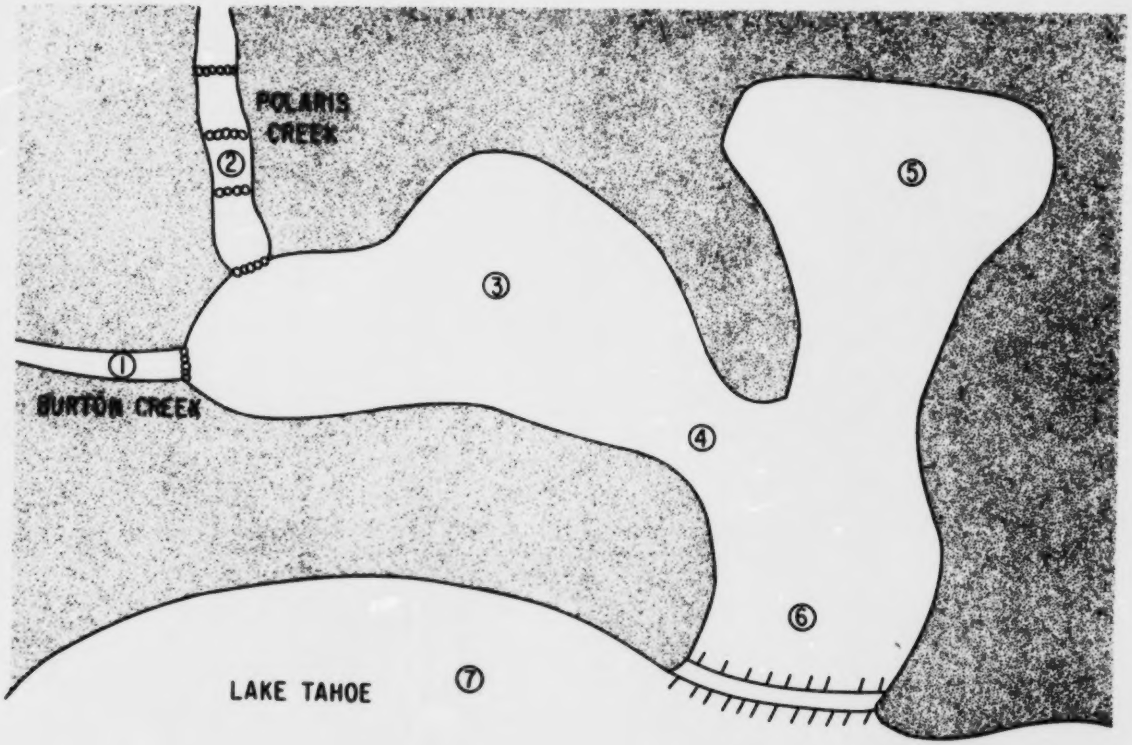

POLARIS CREEK
②
①
BURTON CREEK
③
④
⑤
⑥
⑦
LAKE TAHOE

Figure 70. Map of Star Harbor indicating the sampling stations.

1971 indicate that Polaris Creek (Station 2) carries the higher nutrient concentrations of the two inflowing streams (Table 36). Primary productivity was also highest in this stream while the actual algal biomass was found to be lowest. This indicates that the high nutrient concentrations in the stream are able to support a small population of rapidly growing algae and once the stream enters the harbor, a larger population of algae is allowed to accumulate due to the extended residence time of water in the harbor.

Figure 71 indicates that at the present rate of nutrient recharge into the harbor, there is only limited nutrient removal by algae. There is a notable decrease in nutrients due to dilution as the streams enter the less-nutrient-rich harbor. Once in the lagoon there is neither a significant increase nor decrease in nutrient content of the lagoon waters until it reaches the lake (Station 7). However, this also indicates that the harbor is not causing an increase in nutrients entering the lake since: (1) the streams would carry their high nutrient load to the lake regardless of the presence of the harbor, (2) sediment which provides substrata for bacterial growth is settled out in the harbor, and (3) the growth of planktonic and attached algae requires some loss of nutrients from the water mass.

There was found to be a direct relationship between iron and the growth rate of algae (primary productivity) in the harbor and an inverse relationship between nitrate and primary productivity (Fig. 72). This can be explained by the fact that as iron concentration increases, algal growth rate also increases. An accompanying decrease in nitrate occurs as it is utilized by the growing population. When the available iron has been utilized, the growth rate decreases, allowing a subsequent increase in nitrate. This cycle would seem to indicate that iron is currently the nutrient most limiting the growth of algae in the lagoon. In general, this is in agreement with the findings of Goldman (1964);

TABLE 36. NUTRIENTS, PRIMARY PRODUCTIVITY, AND PHYTOPLANKTON BIOMASS AT THE STAR HARBOR SAMPLING STATIONS. VALUES ARE AVERAGES OF NINE SAMPLES TAKEN BETWEEN 14 APRIL 1970 AND 21 JANUARY 1971.

STATION	NITRATE (μg/l)	PHOSPHATE (μg/l)	IRON (μg/l)	(MG C·M^{-3}·DAY^{-1}) PRIMARY PRODUCTIVITY	(MG·M^{-3}) BIOMASS (OF ALGAE)
1	13.4	22.1	61.5	2.484	162.5
2	40.7	71.0	92.1	4.303	82.3
3	23.2	45.2	73.9	2.167	107.7
4	24.1	46.0	55.7	3.434	100.6
5	22.5	42.0	65.0	4.214	116.8
6	29.9	41.4	64.5	3.810	117.0
7	9.3	10.8	13.3	1.514	90.4

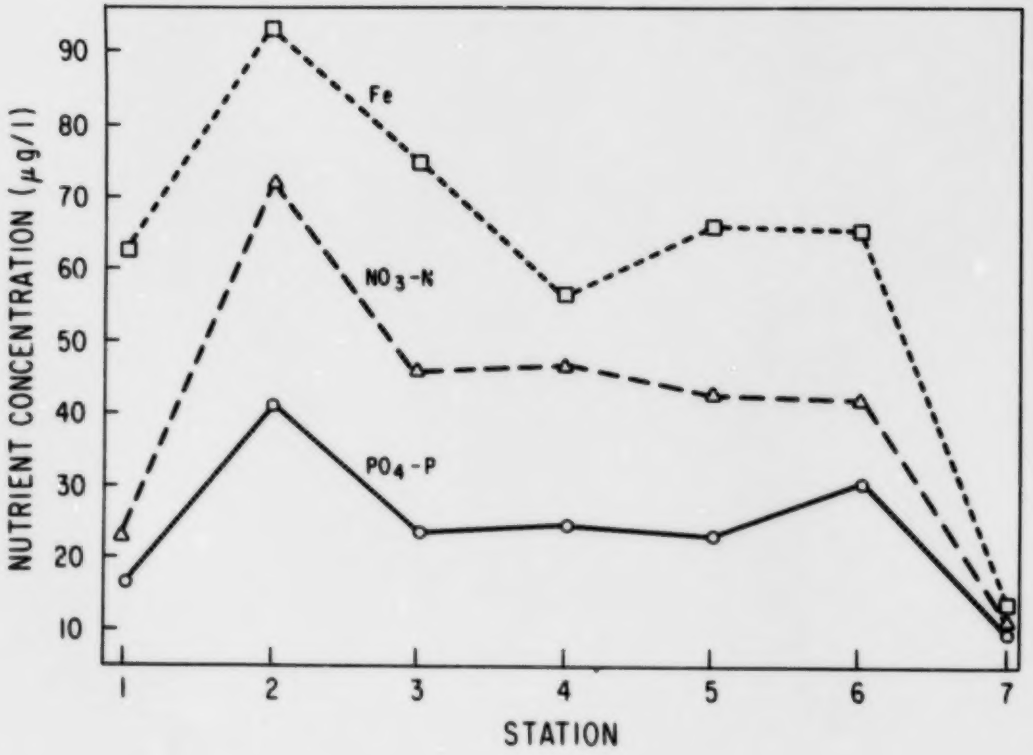


Figure 71. Nutrient concentrations at the Star Harbor sampling stations. Results are averages of nine samples collected between 14 April 1970 and 21 January 1971.

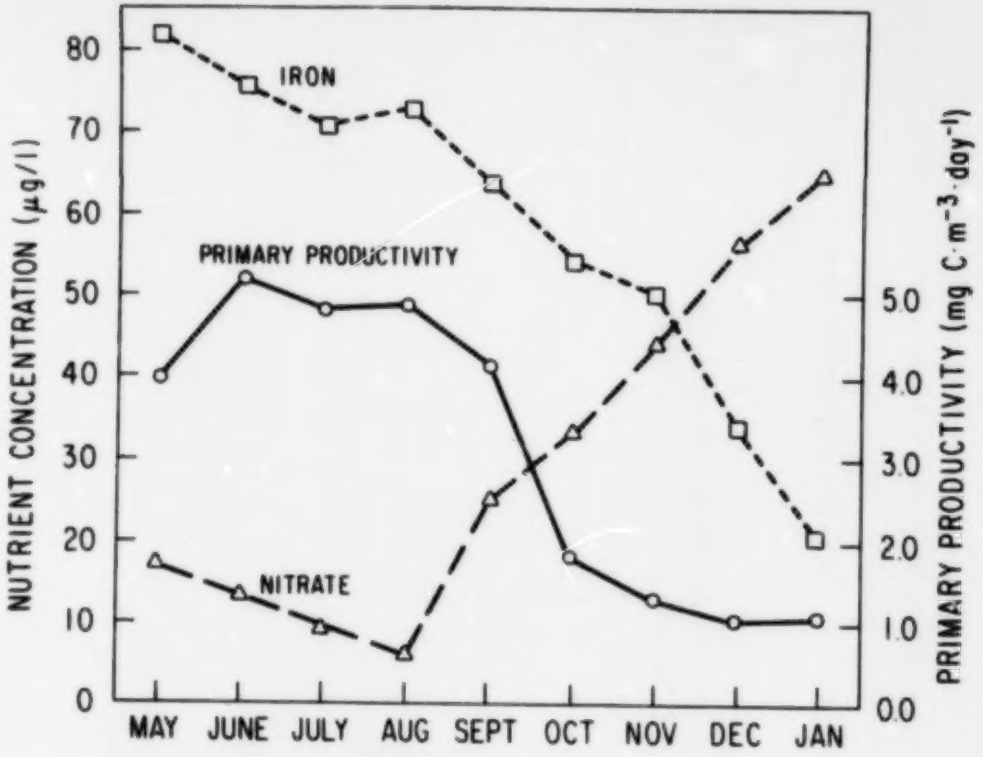


Figure 72. Nutrient-productivity relationships in Star Harbor. A direct relationship was found between iron and primary productivity and an inverse relationship between nitrate and primary productivity.

Goldman and Armstrong (1969); and Goldman, Tunzi, and Armstrong (1969).

A biostimulation culture begun on 30 October 1970 shows that neither Burton Creek nor Polaris Creek stimulate algae growth in Star Harbor (Fig. 73). However, both creeks exhibit high stimulation of Lake Tahoe water with Polaris Creek being more stimulating than Burton Creek (Fig. 74). When water from the harbor was added to lake water, a significant stimulation also occurred (Fig. 75). This indicates that with the present rate of nutrient input and population growth, there would be a stimulation of primary productivity in the lake when the harbor is opened. However, the stimulation will not be as dramatic as in the cultures, due to dilution and current patterns in the lake, and is probably no greater than the influence of the streams alone. The cultures show that there is now a marked difference between the quality of water in the Star Harbor lagoon and that of the lake. Since the lagoon is mainly a mixture of Burton and Polaris Creek water, this finding was expected.

Conclusions

Iron has been found to be the nutrient most limiting the growth of algae within Star Harbor. This knowledge provides a reference point for future management of the system. In any attempt to control the growth of aquatic plants it is first necessary to determine what natural factors are limiting their growth. Once this has been achieved, a workable program may be developed to accurately trace the sources of these factors. Once knowledge is gained of the inputs to a system, the community "metabolism" of these inputs may be studied with a greater understanding. In the case of Lake Tahoe where there is an interest in preventing further accelerated algal growth, an investigation of the inputs, one of which being Star Harbor, is essential in describing a nutrient budget for the lake.

It is stressed here that since iron has been found to be the limiting

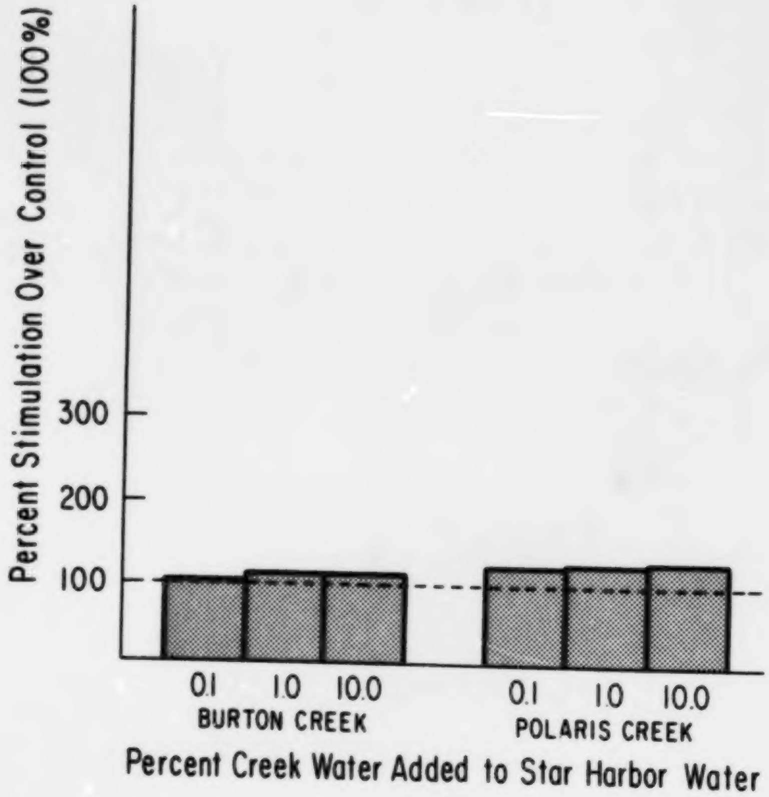


Figure 73. Bioassay of Burton and Polaris Creek water additions to Star Harbor water. Additions of 0.1%, 1.0% and 10.0% did not stimulate algal growth.

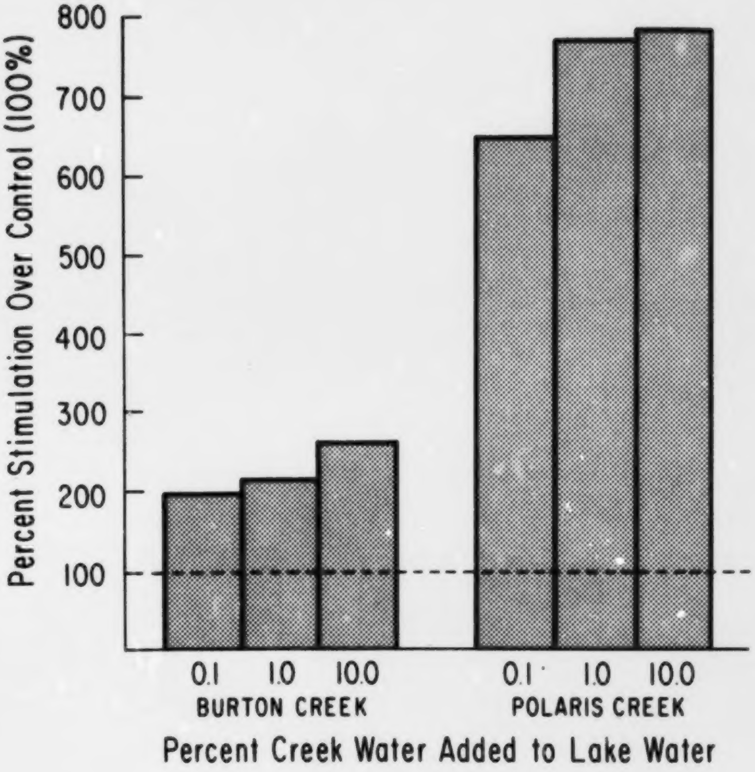


Figure 74. Bioassay of Burton and Polaris Creek water additions to Lake Tahoe water. Additions of 0.1%, 1.0% and 10.0% showed high stimulation of algal growth with Polaris Creek more stimulatory than Burton Creek.

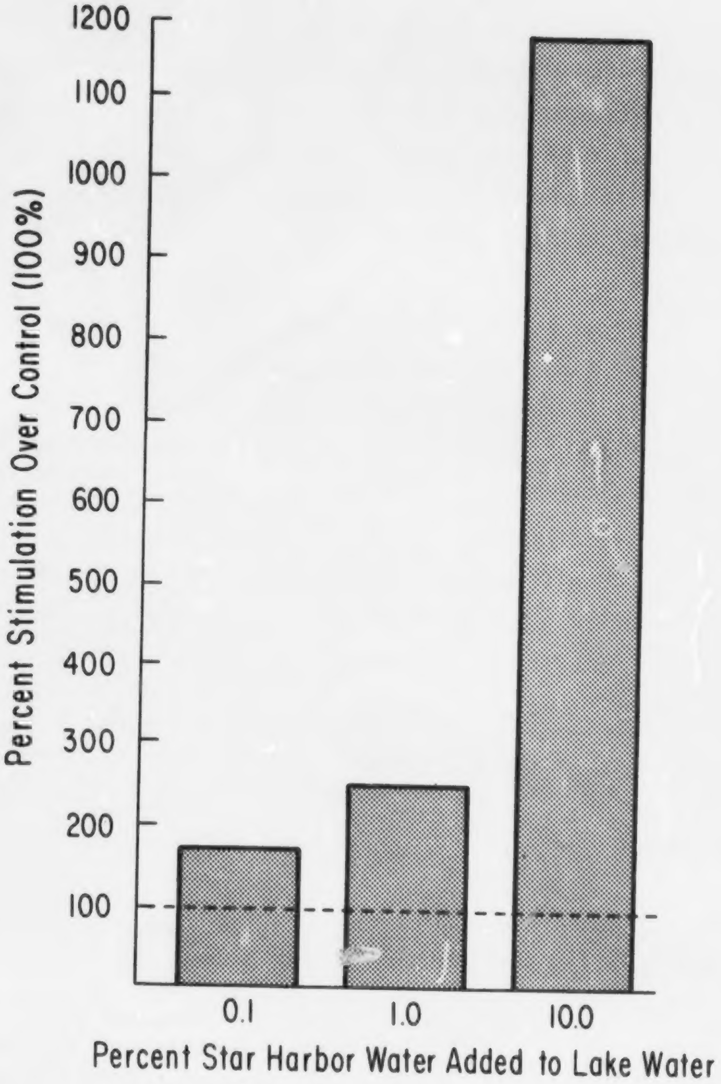


Figure 75. Bioassay of Star Harbor water additions to Lake Tahoe water. Additions of 0.1%, 1.0% and 10.0% showed significant stimulation of algal growth.

nutrient, future research should be concerned with tracing the source of iron to the streams and implementing a program to reduce the flow of iron to the harbor and hence to the lake. It has been shown in this study that the streams flowing into Star Harbor have a biostimulatory effect on the water of Lake Tahoe, therefore it is essential that the nutrient concentrations in the streams be reduced, thereby minimizing primary productivity within the channels.

Plots of iron versus productivity in this study suggested linearity within the ranges measured, but the regressions performed did not pass through zero. It is suggested that a nonlinear model which would produce a sigmoidal curve would be more realistic. At low light intensities and low nutrient levels, the decrease in productivity would be more pronounced, and at high light intensities and high nutrient levels, the rate of increase in productivity would begin to slow down. Once a point is found where productivity would be the lowest with available light and lowest nutrients, a valuable reference point in a management study could be the result.

EFFECTS OF SALMON DECOMPOSITION ON THE ECOLOGY OF A SUBALPINE STREAM

Introduction

Juday et al. (1932) observed that Pacific salmon carcasses are important in resupplying the oligotrophic ecosystems that constitute the nursery areas of young salmon. Nelson and Edmondson (1955) assumed that great quantities of nitrogen, phosphorus, and other important elements are liberated by the decay of spawned-out salmon in Karluk and Bare Lakes, Alaska. Odum (1959) suggested that the reduction in salmon runs has led to an impoverishment of nursery watersheds. Nikolskii (1963) found that the death of sockeye salmon in Lake Dalnie, Russia, led to an increase in phosphate of 10-20 $\mathrm{mg \cdot l^{-1}}$. Krokhin (1967), Donaldson (1967), and Hall (1972) have demonstrated the vital role of migratory fishes in maintaining phosphorus reserves in the headwaters of spawning areas. Narver (1967) felt that a primary production maximum in a salmon-rich bay of Babine Lake, British Columbia, might be explained by an increase in micronutrients from carcass decomposition. Mathisen (1971) concluded that the decline in primary productivity of the lakes of the Nushagak District, Alaska, was probably due to a substantial reduction in the salmon escapement in the lakes. Donaldson (1967) and Mathisen (1972) have postulated that periphyton act as a reservoir for nutrients released by decaying salmon.

It would appear that mineralization of dead salmon may play an important role in the nutrient cycles and energy flow of the nursery watershed. The study reported here presents some evidence directly linking changes in nutrients and production to salmon runs in Taylor Creek, California. Changes in autotrophic and heterotrophic production and water chemistry were followed and related to the spawning and decomposition of the landlocked sockeye, or kokanee, salmon (Onchorhynchus nerka).

Methods

Study Area -

Taylor Creek is a short (8 km), forested stream of the Tahoe drainage basin (Fig. 1). Its source is the outflow of Fallen Leaf Lake, which spills over a small concrete dam and drains into Lake Tahoe. The stream is uniform in size throughout its length, with no significant feeder streams. Because of the stream uniformity and because the dam blocks any further salmon migration into Fallen Leaf Lake itself, it was assumed that any difference in upstream-downstream biological or mineral activity might be attributed to the salmon decomposition. Accordingly, phosphate, nitrate, primary production, and heterotrophic activity were monitored at monthly intervals from 1 October 1970 through

4 September 1971 at lower, middle, and upstream stations. In January 1971, ammonia and iron were also assayed.

Analytical Methods -

Autotrophic carbon uptake by free-floating phytoplankton was measured with the ^{14}C method (Goldman 1963). Heterotrophic activity was measured using 2-^{14}C-acetate uptake (Paerl and Goldman 1972a). Samples were collected in the field, kept cool in the dark, and transported back to the laboratory for analysis.

Water from each station was collected in polyethylene jugs and frozen until analysis. Nitrate was measured by cadmium reduction (Strickland and Parsons 1968), phosphate by ammonium molybdate (Murphy and Riley 1962) with sulfuric acid used for the hydrolysis of the particulate fraction, iron by bathyphenanthroline (Strickland and Parsons 1968), and ammonia by a hypochlorite method (Strickland and Parsons 1968). Filtration was at a low vacuum through acid-soaked and rinsed GFC filters.

Estimates of daily streamflow were obtained from the U.S. Geological Survey. Spawner abundance (escapement) estimates were provided by the California Department of Fish and Game.

Results

Visual Observations -

The kokanee salmon started to ascend Taylor Creek in late September and October 1970, with the bulk of the spawning in November and December. The accumulation of salmon carcasses reached a peak in January 1971 with decomposition completed by the end of March. At middle Taylor and especially at lower Taylor Creek, a very heavy bloom of the periphyton Ulothrix occurred in January and February 1971. Escapement was estimated at 14,000 fish and the average stream flow from October through March was 30.2 cfs.

Productivity -

Figure 76 shows the patterns of stream-borne phytoplankton carbon fixation in 1970-71. There was little difference between stations, with values averaging 1-4 mg $C\cdot m^{-2}\cdot hr^{-1}$. In January 1971, the time of peak carcass decomposition, there was a distinct downstream increase, with a maximum at the lower Taylor Creek station of 13.8 mg $C\cdot m^{-2}\cdot hr^{-1}$.

Coinciding with the downstream peak of productivity in January 1971 was a peak of heterotrophic activity (Fig. 76), except the gradient was spread over December and February. Heterotrophic activity at upper Taylor Creek remained very low until June, when it surpassed the other stations. This is a time of much pleasure boating, hiking, and other recreational activity on Fallen Leaf Lake and its watershed. The heterotrophic activity is probably a reflection of increased organics in the lake water entering the stream.

Water chemistry -

A limnological survey of the streams of the Tahoe drainage basin in 1969-70 revealed a peak of phosphate in Taylor Creek at the time of salmon spawning. This peak was not seen in the other, salmon-free, streams of the basin at that time (Goldman 1970c). This nutrient pattern was maintained during the 1970-71 study reported here. Nitrate concentrations increased downstream to a February maximum of 19 $\mu g\cdot l^{-1}$ (Fig.77). By May Taylor Creek was relatively homogenous with respect to nitrate at about 5 $\mu g\cdot l^{-1}$. The same general pattern was shown by phosphate concentrations (Fig. 77). Values are erratic and might be attributed to difficulties in the analysis (cf. Chamberlin and Shapiro 1973). However, downstream maximums of about 14 $\mu g\cdot l^{-1}$ were observed during the time of decomposition, while upstream values were only about 5 $\mu g\cdot l^{-1}$. The stream also became uniform for phosphate by late spring.

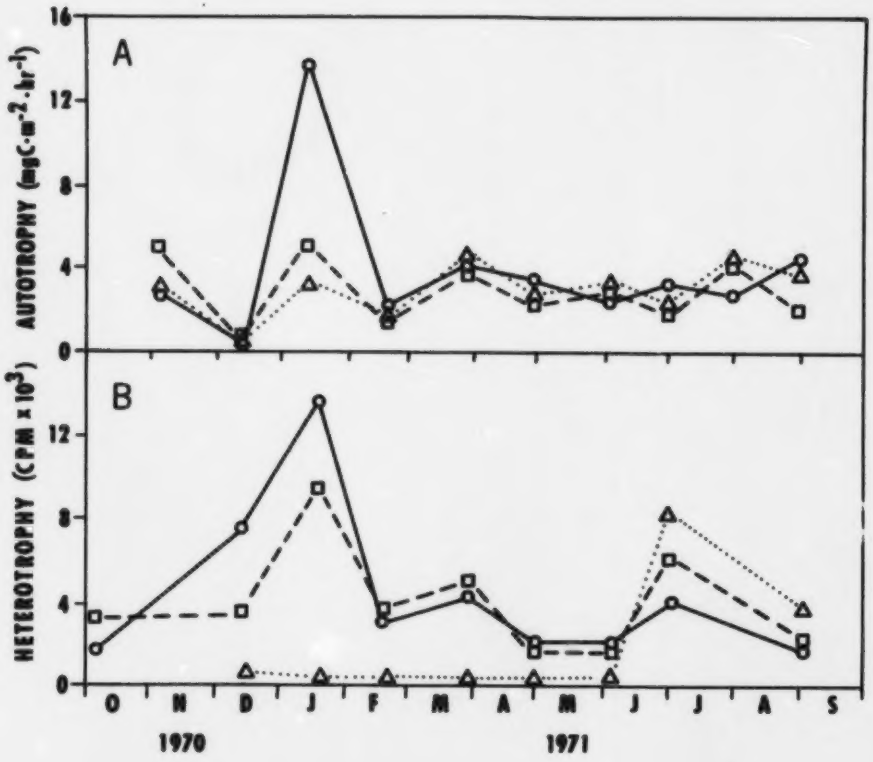


Figure 76. Seasonal autotrophic and heterotrophic activity of Taylor Creek between October 1970 and September 1971. At lower (O), middle (□), and upper (△) stations.

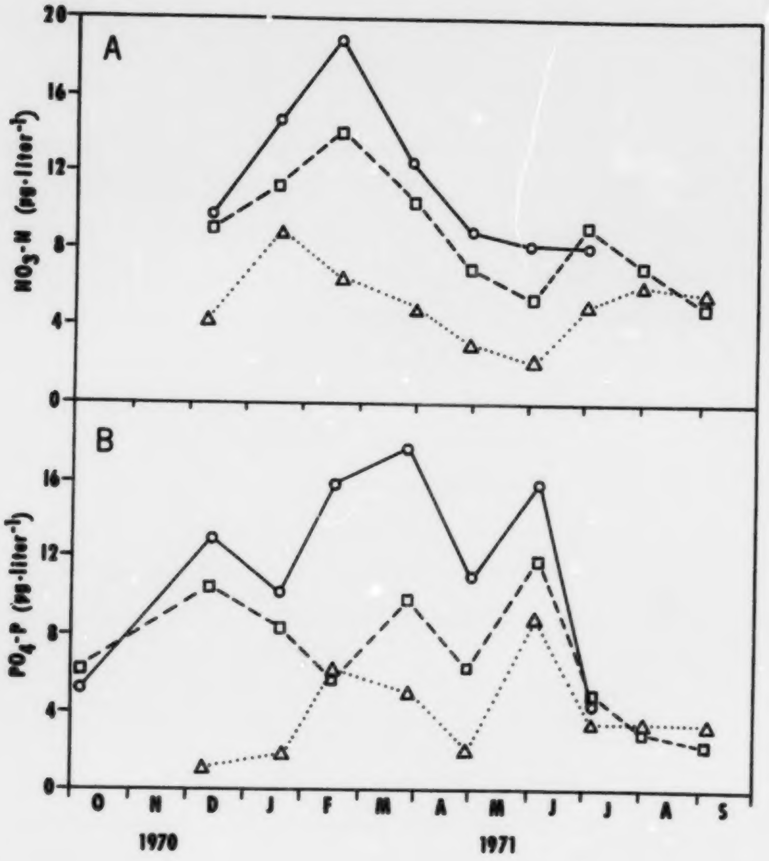


Figure 77. Seasonal nitrate-nitrogen and phosphate-phosphorus between October 1970 and September 1971. At lower (0), middle (□), and upper (△) stations in Taylor Creek.

Higher concentrations of both nitrate and phosphate were maintained after the peak of carcass decomposition, possibly due to slow release of nutrients by periphyton. In January, ammonia concentrations were 6, 26, and 29 $\mu g \cdot l^{-1}$ at the upper, middle, and downstream stations, respectively. Iron concentrations were at the limit of concentration of 15 $\mu g \cdot l^{-1}$ at all stations.

An approximation of the phosphorus available through the decomposition of salmon carcasses may be calculated from the streamflow and escapement estimates. Assuming an average wet weight of 1750 g per fish with 0.364% phosphorus (Donaldson 1967), yields 8.92×10^{10} µg from a salmon run of 14,000 fish. The water volume over the time of the residence of the salmon in the stream (October through March) was 1.34×10^{10} liters, given the average flow rate of 30.2 cfs. Dilution of the phosphorus from the fish in that volume of water gives a final concentration of about 7 $\mu g \cdot l^{-1}$. The approximate difference between upstream and downstream concentrations of phosphate was 10 $\mu g \cdot l^{-1}$, so it would be possible for the salmon decomposition to have supplied the difference. Periphyton would have sequestered an unknown amount of phosphate and nitrate.

Discussion

That the sockeye salmon are indeed responsible for modifying the ecology of Taylor Creek might be inferred from: (1) An increase of phosphate in Taylor Creek coincident with the salmon run, which was not observed at the same time in other salmon-free streams of the basin. (2) Carbon fixation, bacterial heterotrophy, and periphyton activity was greatest at the peak of salmon decomposition in mid-winter (an unusual time for heavy blooms). Both metabolism and nutrient concentrations were greatest downstream at this time. The only difference noted between the upstream and downstream stations was the presence of salmon.

(3) Calculations show that the decomposition of salmon was sufficient to account for the difference between upstream and downstream phosphorus.

From the above, some aspects of the role of the kokanee salmon in the mineral and energy flows of Taylor Creek are clear. The salmon migrate up Taylor Creek from Lake Tahoe to spawn and die. The presence of the energy-rich carcasses stimulates bacterial activity, leading to the release of inorganic nitrogen, phosphorus, and presumably many other macro- and micronutrients. The minerals released stimulate a mid-winter bloom of phytoplankton and periphyton. The periphyton hold the nutrients in the spawning stream to be released slowly after the final decay of the salmon. Bacterial and algal stimulation in Tahoe by tributary inflow is now well documented in Lake Tahoe (Goldman et al. 1974). These nutrients may be important in maintaining the fertility of the nursery area of the lake adjacent to the stream mouth where the smolts develop, after hatching and migrating to the lake.

SECTION XIII

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SECTION XIV

PUBLICATIONS, MANUSCRIPTS, REPORTS, AND THESES

Published

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APPENDIX A

LAKE TAHOE TEMPERATURE-DEPTH PROFILES

Temperature (°C) vs. sampling depth at the index station of Lake Tahoe, 1967-1970.

LAKE TAHOE 1967 *****TEMPERATURE PROFILES*****
****

DEPTH (M)	8/ 9	8/25	9/ 2	9/ 7	9/14	9/21	9/29	11/ 1	11/15	12/ 1
0.	19.25	20.50	20.00	19.00	18.00	16.50	16.50	11.50	10.50	8.50
3.	19.00	20.50	19.50	18.50	17.50	16.50	16.50	11.50	10.50	8.50
6.	19.00	20.00	19.50	18.00	17.50	16.50	16.50	11.50	10.50	8.50
9.	18.75	20.00	19.00	17.50	17.50	16.50	16.50	11.50	10.50	8.00
12.	18.75	20.00	19.00	17.00	17.25	16.25	16.25	11.50	10.50	8.00
15.	18.50	19.50	18.50	16.50	17.00	16.25	15.00	11.50	10.50	7.75
18.	15.75	14.00	15.00	12.50	17.00	16.25	14.50	11.50	10.25	7.75
21.	11.75	12.00	13.00	10.50	14.00	16.00	12.75	11.50	10.25	7.50
24.	10.25	10.50	12.00	10.00	9.50	10.00	11.00	11.25	10.25	7.50
27.	9.25	8.50	9.50	9.00	8.00	9.00	10.00	11.25	10.25	7.50
30.	8.75	8.00	8.50	6.50	7.50	7.50	9.00	11.25	10.25	7.50
33.	7.75	7.25	8.00	8.00	7.00	7.00	8.50	11.00	10.25	7.50
36.	7.25	6.75	7.00	7.50	6.50	6.50	7.50	10.50	10.00	7.25
39.	6.75	6.50	6.50	7.00	6.00	6.25	6.50	10.00	9.75	7.25
42.	6.75	6.00	6.25	6.50	5.75	6.25	6.00	9.50	9.75	7.25
45.	6.25	5.75	6.00	6.50	5.75	6.00	6.00	9.00	9.50	7.25
48.	6.25	5.50	6.00	6.00	5.50	5.75	5.75	8.50	9.25	7.25
51.	6.25	5.25	5.75	6.00	5.50	5.50	5.50	7.50	9.25	7.00
54.	5.75	5.25	5.75	6.00	5.25	5.50	5.50	7.00	9.00	7.00
57.	5.75	5.00	5.50	5.75	5.25	5.50	5.00	6.25	8.50	6.75
60.	5.75	5.00	5.50	5.50	5.00	5.50	5.00	6.25	8.00	6.75
63.	5.75	5.00	5.50	5.50	5.00	5.25	5.00	6.00	7.50	6.50
66.	5.75	5.00	5.50	5.25	5.00	5.00	5.00	5.75	7.00	6.25
69.	5.75	5.00	5.25	5.25	5.00	5.00	5.00	5.50	6.50	6.25
72.	5.75	5.00	5.00	5.00	5.00	5.00	5.00	5.25	6.00	6.00
75.	5.75	5.00	5.00	5.00	5.00	5.00	4.75	5.25	5.75	6.00
78.	5.75	5.00	5.00	5.00	5.00	5.00	4.75	5.00	5.50	5.75
81.	5.75	5.00	5.00	5.00	5.00	5.00	4.75	5.00	5.50	5.50
84.	5.75	5.00	5.00	5.00	5.00	5.00	4.75	5.00	5.25	5.50
87.	5.75	5.00	5.00	5.00	5.00	5.00	4.75	5.00	5.25	5.25
90.	5.75	5.00	5.00	5.00	5.00	5.00	4.75	5.00	5.00	5.25
93.	5.75	4.75	5.00	5.00	5.00	4.75	4.50	4.75	5.00	5.00
96.	5.75	4.75	5.00	5.00	4.75	4.75	4.50	4.75	5.00	5.00
99.	5.75	4.75	5.00	5.00	4.75	4.75	4.50	4.75	4.75	5.00
102.	5.75	4.75	5.00	5.00	4.75	4.75	4.50	4.75	4.75	4.75
105.	5.75	4.75	5.00	5.00	4.75	4.75	4.50	4.75	4.75	4.75
108.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
111.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
114.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
117.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
120.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
123.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
126.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
129.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
132.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75
135.	5.75	4.75	4.75	5.00	4.75	4.75	4.50	4.75	4.75	4.75

LAKE TAHOE 1968 *****TEMPERATURE PROFILES******
****

DEPTH (M)	1/24	2/ 8	2/14	2/21	2/26	3/ 6	3/20	3/26	4/ 2	4/11	4/14	4/25	5/ 1	5/ 8	5/14	5/22	5/29	6/ 5
0.	4.75	5.00	4.50	4.50	5.00	5.00	5.00	4.50	4.75	6.00	5.00	5.50	7.00	7.00	8.00	6.00	8.75	9.75
3.	4.75	5.00	4.50	4.50	5.00	5.00	5.00	4.50	4.75	6.00	5.00	5.50	7.00	7.00	7.75	6.00	8.75	9.50
6.	4.75	4.50	4.50	4.50	5.00	4.75	4.75	4.50	4.75	6.00	5.00	5.50	6.75	6.75	7.75	6.00	8.50	9.50
9.	4.75	4.50	4.50	4.50	4.75	4.75	4.75	4.50	4.75	6.00	5.00	5.25	6.00	6.75	7.75	5.75	8.50	9.25
12.	4.75	4.50	4.50	4.50	4.75	4.75	4.75	4.50	4.75	6.00	5.00	5.25	6.00	6.75	7.50	5.75	8.50	8.75
15.	4.75	4.50	4.50	4.50	4.75	4.75	4.50	4.50	4.75	5.75	5.00	5.25	5.75	6.50	7.50	5.75	8.25	8.50
18.	4.75	4.50	4.50	4.50	4.75	4.75	4.50	4.50	4.75	5.50	5.00	5.25	5.50	6.50	7.25	5.75	8.00	8.50
21.	4.75	4.50	4.50	4.50	4.75	4.75	4.50	4.50	4.75	5.25	5.00	5.25	5.50	6.25	7.25	5.75	8.00	8.25
24.	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.50	4.75	5.00	5.00	5.25	5.50	6.25	7.25	5.75	7.75	8.00
27.	4.50	4.50	4.50	4.50	4.50	4.75	4.50	4.50	4.75	5.00	5.00	5.25	5.50	6.00	7.25	5.75	7.75	7.75
30.	4.50	4.50	4.50	4.50	4.50	4.75	4.50	4.50	4.75	5.00	5.00	5.00	5.25	6.00	7.25	5.75	7.50	7.50
33.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	5.00	5.00	5.00	5.25	6.00	7.25	5.75	7.50	7.25
36.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	5.00	5.00	5.00	5.25	6.00	7.25	5.75	7.25	7.25
39.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	5.00	5.00	5.00	5.25	5.75	7.00	5.75	7.00	7.00
42.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	5.00	5.00	5.00	5.00	5.75	7.00	5.75	6.75	7.00
45.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	5.00	5.00	5.00	5.00	5.75	6.75	5.75	6.75	6.75
48.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	5.00	5.75	6.75	5.75	6.50	6.50
51.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	5.00	5.75	6.75	5.75	6.50	6.50
54.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	5.00	5.50	6.75	5.75	6.50	6.25
57.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	5.00	5.50	6.50	5.75	6.25	6.25
60.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	4.75	5.50	6.50	5.75	6.25	6.25
63.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	4.75	5.50	6.25	5.75	6.25	6.25
66.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	4.75	5.50	6.25	5.75	6.00	6.25
69.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	4.75	5.50	6.25	5.75	6.00	6.00
72.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	5.00	5.00	4.75	5.25	6.25	5.75	5.75	5.75
75.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.75	5.00	6.25	5.75	5.75	5.75
78.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	5.00	6.25	5.75	5.75	5.75
81.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	5.00	6.25	5.75	5.75	5.75
84.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	5.00	6.00	5.75	5.75	5.75
87.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	5.00	6.00	5.75	5.75	5.75
90.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	5.00	5.75	5.75	5.75	5.75
93.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	5.00	5.75	5.75	5.75	5.75
96.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	5.00	5.75	5.75	5.50	5.50
99.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.75	5.75	5.50	5.50
102.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.75	5.50	5.50
105.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.50	5.50	5.25
108.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.50	5.25	5.25
111.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.50	5.25	5.25
114.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.50	5.25	5.25
117.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.50	5.25	5.25
120.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.50	5.25	5.25
123.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.50	5.25	5.25
126.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.25	5.25	5.25
129.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.25	5.25	5.25
132.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.25	5.25	5.25
135.	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.75	4.75	4.50	4.75	5.50	5.25	5.25	5.25

LAKE TAHOE 1968 ******TEMPERATURE PROFILES******

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DEPTH (M)	6/12	6/19	6/26	7/ 4	7/11	7/17	7/24	7/31	8/ [illegible]	8/12	9/ 2	9/17	9/26	10/15	10/19	10/27	11/ 2	12/ 1
0.	10.50	15.00	15.25	15.50	16.75	16.00	17.00	19.00	19.00	19.00	16.50	16.00	15.75	13.00	13.50	13.00	12.00	8.75
3.	10.25	14.00	15.00	15.25	16.50	15.75	16.75	18.75	18.75	19.00	16.25	16.00	15.75	12.75	13.00	13.00	12.00	8.75
6.	10.25	12.75	14.75	15.25	15.50	15.25	16.50	18.75	18.50	19.00	16.25	16.00	15.75	12.75	12.50	12.75	12.00	8.75
9.	10.00	12.50	14.00	15.00	14.25	14.75	16.00	18.50	18.00	18.75	16.25	16.00	15.75	12.50	12.50	12.75	12.00	8.75
12.	9.75	11.50	13.50	14.50	13.25	14.75	15.75	17.50	17.50	18.50	16.00	16.00	15.50	12.50	12.25	12.75	12.00	8.75
15.	9.50	10.75	12.50	13.50	12.75	14.50	15.50	15.50	16.50	18.25	15.75	15.75	15.50	12.50	12.25	12.75	12.00	8.75
18.	9.25	10.50	11.25	13.00	12.25	14.25	14.75	13.50	15.00	17.25	15.25	15.75	15.50	12.50	12.25	12.75	12.00	8.75
21.	8.75	10.25	10.75	12.00	12.00	13.00	14.75	13.00	13.50	15.00	14.75	15.75	15.50	12.50	12.25	12.75	11.75	8.75
24.	8.50	10.00	9.75	10.75	11.25	12.50	12.50	11.50	12.50	13.25	14.50	15.50	15.50	12.50	12.25	12.75	11.75	8.75
27.	8.25	9.75	9.75	10.00	10.25	11.75	11.00	10.50	11.00	12.25	14.00	15.00	15.25	12.25	12.25	12.50	11.50	8.75
30.	8.00	9.75	9.50	9.25	9.75	11.00	10.50	10.00	10.50	11.25	12.50	13.50	14.50	12.25	12.25	12.50	11.25	8.75
33.	7.75	9.50	8.75	8.75	9.25	10.00	9.50	9.50	9.50	10.25	11.75	11.00	13.50	12.00	12.25	12.50	10.50	8.75
36.	7.50	8.75	8.25	8.50	8.50	9.75	9.00	9.00	8.50	9.50	11.50	9.50	12.00	11.75	12.00	12.50	10.00	8.75
39.	7.25	8.25	8.00	8.00	8.00	8.75	8.50	8.75	8.25	9.25	11.00	8.75	11.25	11.50	11.75	12.25	9.25	8.75
42.	6.75	7.75	7.50	8.00	7.50	8.50	8.25	8.50	8.00	9.00	10.50	8.50	10.50	11.25	11.50	12.00	8.25	8.75
45.	6.50	7.50	7.00	7.75	7.00	8.25	8.00	8.00	7.75	8.50	10.00	8.25	10.25	10.75	10.00	11.75	7.75	8.75
48.	6.25	7.25	6.75	7.50	6.75	8.00	7.50	7.75	7.50	8.25	9.25	8.00	10.00	10.25	9.00	10.25	7.50	8.50
51.	6.25	7.25	6.75	7.25	6.75	7.50	7.00	7.50	7.25	8.00	9.00	7.75	9.75	10.00	8.75	9.25	7.25	8.50
54.	6.25	7.00	6.50	7.00	6.50	7.25	7.00	7.25	7.00	8.00	8.75	7.50	9.25	9.25	8.00	8.75	7.00	8.50
57.	6.00	6.75	6.25	6.75	6.50	7.25	6.75	7.25	6.75	7.75	8.50	7.25	9.00	8.25	7.75	8.25	6.75	8.50
60.	5.75	6.75	6.25	6.75	6.25	7.00	6.50	7.00	6.50	7.50	8.25	7.25	8.75	7.50	7.75	8.00	6.75	8.25
63.	5.75	6.50	6.00	6.75	6.25	6.75	6.50	6.75	6.25	7.25	8.25	7.00	8.75	7.00	7.50	7.75	6.50	8.00
66.	5.75	6.25	5.75	6.50	6.00	6.50	6.25	6.50	6.25	7.25	8.00	6.75	8.50	7.00	7.00	7.50	6.25	7.50
69.	5.75	6.25	5.75	6.50	6.00	6.50	6.00	6.50	6.25	7.00	7.75	6.75	8.25	6.75	6.50	7.25	6.25	7.50
72.	5.75	6.00	5.75	6.25	5.75	6.25	6.00	6.25	6.25	7.00	7.75	6.50	8.25	6.50	6.25	7.00	6.25	7.25
75.	5.75	6.00	5.75	6.25	5.75	6.25	5.75	6.25	6.25	6.75	7.50	6.50	8.00	6.25	6.00	7.00	6.00	7.25
78.	5.75	5.75	5.75	6.00	5.75	6.25	5.75	6.25	6.00	6.25	7.25	6.50	7.75	6.00	5.75	6.75	6.00	7.00
81.	5.75	5.75	5.75	5.75	5.75	6.00	5.75	6.25	6.00	6.50	7.00	6.25	7.50	6.00	5.75	6.75	5.75	7.00
84.	5.50	5.75	5.50	5.75	5.75	6.00	5.50	6.00	6.00	6.50	7.00	6.25	7.50	5.75	5.75	6.50	5.75	6.75
87.	5.50	5.75	5.50	5.75	5.50	5.75	5.50	6.00	5.75	6.25	6.75	6.25	7.25	5.75	5.50	6.50	5.75	6.75
90.	5.50	5.75	5.50	5.75	5.50	5.75	5.50	6.00	5.75	6.00	6.75	6.25	7.00	5.75	5.50	6.25	5.75	6.50
93.	5.50	5.75	5.50	5.75	5.50	5.75	5.25	6.00	5.75	5.75	6.75	6.25	7.00	5.75	5.50	6.25	5.75	6.25
96.	5.50	5.50	5.25	5.75	5.50	5.75	5.25	6.00	5.75	5.75	6.50	6.25	7.00	5.75	5.25	6.25	5.75	6.00
99.	5.50	5.50	5.25	5.50	5.50	5.50	5.25	5.75	5.75	5.75	6.50	6.25	6.75	5.50	5.25	6.00	5.75	6.00
102.	5.50	5.50	5.25	5.50	5.50	5.50	5.25	5.75	5.75	5.75	6.50	6.25	6.75	5.50	5.25	6.00	5.75	5.75
105.	5.50	5.50	5.25	5.50	5.50	5.50	5.25	5.75	5.75	5.75	6.25	6.00	6.75	5.50	5.25	5.75	5.50	5.75
108.	5.25	5.50	5.25	5.50	5.25	5.50	5.25	5.75	5.75	5.75	6.25	6.00	6.50	5.50	5.25	5.75	5.50	5.50
111.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.75	6.25	6.00	6.50	5.50	5.25	5.75	5.50	5.50
114.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.75	6.25	6.00	6.50	5.50	5.25	5.75	5.50	5.50
117.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.75	6.25	6.00	6.50	5.50	5.25	5.75	5.50	5.50
120.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.50	6.25	6.00	6.50	5.50	5.25	5.75	5.50	5.50
123.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.50	6.25	6.00	6.50	5.50	5.25	5.75	5.50	5.25
126.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.50	6.00	6.00	6.50	5.50	5.25	5.75	5.50	5.25
129.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.50	6.00	6.00	6.50	5.50	5.25	5.75	5.50	5.25
132.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.50	6.00	6.00	6.50	5.50	5.00	5.75	5.50	5.25
135.	5.25	5.25	5.25	5.50	5.25	5.25	5.00	5.75	5.75	5.50	6.00	6.00	6.50	5.50	5.00	5.75	5.50	5.25

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LAKE TAHOE 1968  *****TEMPERATURE PROFILES******
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DEPTH 12/ 7  12/22
 (M)
   0.   8.75   7.00
   3.   8.75   7.00
   6.   8.75   7.00
   9.   8.50   7.00
  12.   8.50   7.00
  15.   8.50   7.00
  18.   8.50   7.00
  21.   8.50   7.00
  24.   8.50   6.75
  27.   8.50   6.75
  30.   8.50   6.75
  33.   8.50   6.75
  36.   8.50   6.75
  39.   8.50   6.75
  42.   8.50   6.75
  45.   8.50   6.75
  48.   8.50   6.75
  51.   8.50   6.75
  54.   8.50   6.75
  57.   8.50   6.75
  60.   8.25   6.75
  63.   8.25   6.75
  66.   8.00   6.75
  69.   8.00   6.75
  72.   7.75   6.75
  75.   7.50   6.75
  78.   7.00   6.75
  81.   6.75   6.50
  84.   6.50   6.50
  87.   6.25   6.50
  90.   6.00   6.50
  93.   6.00   6.50
  96.   5.75   6.25
  99.   5.75   6.00
 102.   5.75   6.00
 105.   5.50   6.00
 108.   5.50   6.00
 111.   5.50   5.75
 114.   5.50   5.75
 117.   5.50   5.75
 120.   5.50   5.75
 123.   5.25   5.75
 126.   5.25   5.75
 129.   5.25   5.75
 132.   5.25   5.50
 135.   5.25   5.50
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LAKE TAHOE 1969 *****TEMPERATURE PROFILES*****

DEPTH (M)	1/16	2/ 1	2/15	3/ 2	3/15	3/30	4/13	4/25	5/ 9	5/23	6/ 7	6/20	7/ 1	7/15	7/22	7/30	8/14	8/27
0.	5.75	4.75	5.00	5.00	5.25	5.50	5.50	6.00	9.25	13.50	14.25	15.50	16.50	16.50	19.75	20.50	20.50	20.50
3.	5.75	5.00	5.00	5.00	5.25	5.50	5.75	5.75	8.50	12.25	14.00	15.00	16.00	16.00	19.00	20.50	20.25	20.25
6.	5.75	5.50	5.25	5.00	5.25	5.25	5.75	5.75	8.00	11.50	13.50	14.75	15.75	15.50	18.75	20.00	20.00	20.25
9.	5.75	5.50	5.25	5.00	5.00	5.25	5.50	5.25	7.50	10.50	12.50	14.50	15.50	15.00	17.50	19.00	20.00	20.25
12.	5.75	5.50	5.25	5.00	5.00	5.25	5.50	5.25	7.00	10.00	12.00	12.50	15.50	14.00	16.00	18.50	19.75	20.00
15.	5.75	5.25	5.25	5.00	5.00	5.00	5.50	5.00	6.75	9.75	11.50	11.50	15.50	13.00	14.50	15.50	19.00	20.00
18.	5.75	5.25	5.25	5.00	5.00	5.00	5.50	5.00	6.75	9.50	10.50	10.50	15.25	12.25	13.75	14.50	15.50	19.75
21.	5.75	5.25	5.25	5.00	5.00	5.00	5.50	5.00	6.50	9.50	10.50	9.25	12.50	11.00	13.00	13.75	15.00	17.00
24.	5.75	5.25	5.25	5.00	5.00	5.00	5.50	5.00	6.50	9.25	10.25	8.50	11.00	10.00	11.50	12.75	13.00	15.00
27.	5.75	5.25	5.25	5.00	5.00	5.00	5.50	5.00	6.50	9.00	10.00	8.25	10.75	9.50	10.50	12.00	11.75	14.00
30.	5.75	5.25	5.25	4.75	5.00	5.00	5.50	5.00	6.50	9.00	9.75	7.75	10.00	8.75	9.75	11.00	10.00	12.00
33.	5.75	5.25	5.25	4.75	5.00	4.75	5.50	5.00	6.25	8.75	9.25	7.50	9.75	8.50	9.00	9.50	9.25	11.00
36.	5.75	5.25	5.25	4.75	5.00	4.75	5.50	4.75	6.25	8.75	9.00	7.50	9.50	8.00	8.50	9.00	8.50	10.00
39.	5.75	5.25	5.25	4.75	5.00	4.75	5.50	4.75	6.25	8.50	8.75	7.00	9.00	7.75	8.50	8.25	8.00	9.50
42.	5.75	5.25	5.25	4.75	5.00	4.75	5.50	4.75	6.00	8.25	8.25	7.00	8.50	7.50	8.00	8.00	7.50	8.75
45.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.75	8.00	8.25	6.75	8.25	7.25	7.75	7.75	7.25	8.50
48.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.75	7.75	8.00	6.50	8.00	7.00	7.75	7.50	7.00	8.25
51.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.50	7.50	8.00	6.25	7.50	6.75	7.50	7.25	7.00	8.00
54.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.50	7.50	7.75	6.25	7.50	6.50	7.50	7.00	6.75	8.00
57.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.50	7.50	7.75	6.00	7.50	6.50	7.50	7.00	6.50	7.75
60.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.50	7.50	7.75	6.00	7.25	6.25	7.25	6.75	6.50	7.75
63.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.50	7.25	7.50	5.75	7.25	6.00	7.25	6.50	6.25	7.50
66.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.50	7.25	7.50	5.75	7.00	6.00	7.00	6.50	6.25	7.50
69.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.25	7.25	7.50	5.75	7.00	6.00	7.00	6.50	6.00	7.00
72.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.25	7.00	7.25	5.75	6.75	6.00	7.00	6.50	6.00	7.00
75.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.25	7.00	7.25	5.75	6.75	6.00	7.00	6.50	6.00	7.00
78.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.75	5.25	7.00	7.25	5.75	6.75	6.00	6.75	6.50	6.00	7.00
81.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.50	5.25	7.00	7.25	5.50	6.75	6.00	6.75	6.50	6.00	7.00
84.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.50	5.25	7.00	7.00	5.25	6.75	5.75	6.75	6.25	6.00	7.00
87.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.50	5.25	7.00	7.00	5.25	6.75	5.75	6.50	6.25	6.00	7.00
90.	5.75	5.25	5.25	4.75	5.00	4.75	5.25	4.50	5.25	6.75	7.00	5.25	6.75	5.75	6.50	6.25	5.75	7.00
93.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.25	6.75	7.00	5.25	6.75	5.75	6.50	6.00	5.75	6.50
96.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.25	6.75	6.75	5.25	6.50	5.75	6.50	6.00	5.50	6.50
99.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.25	6.75	6.75	5.25	6.50	5.75	6.50	6.00	5.50	6.50
102.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.25	6.75	6.75	5.25	6.50	5.50	6.50	6.00	5.50	6.50
105.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.75	6.75	5.25	6.50	5.50	6.50	6.00	5.50	6.50
108.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.75	6.75	5.00	6.50	5.50	6.50	6.00	5.50	6.50
111.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.75	6.75	5.00	6.50	5.50	6.50	6.00	5.50	6.50
114.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.75	6.75	5.00	6.50	5.50	6.50	6.00	5.50	6.50
117.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.75	6.75	5.00	6.50	5.50	6.50	6.00	5.50	6.50
120.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.50	6.50	5.00	6.50	5.50	6.50	5.75	5.50	6.50
123.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.50	6.50	5.00	6.50	5.50	6.25	5.75	5.50	6.25
126.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.50	6.50	5.00	6.50	5.25	6.25	5.75	5.50	6.25
129.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.50	6.50	5.00	6.50	5.25	6.25	5.75	5.50	6.25
132.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.50	6.50	5.00	6.50	5.25	6.25	5.75	5.50	6.25
135.	5.75	5.25	5.25	4.75	5.00	4.75	5.00	4.50	5.10	6.50	6.50	5.00	6.50	5.25	6.25	5.75	5.50	6.25

LAKE TAHOE 1969 *****TEMPERATURE PROFILES*****
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DEPTH (M)	9/ 3	10/10	10/22	10/28	11/12	11/23	12/ 5	12/16	12/26
0.	19.50	12.25	11.50	11.25	10.00	9.00	8.50	7.25	6.00
3.	19.50	12.25	11.25	11.00	9.75	9.00	8.50	7.25	6.00
6.	19.50	12.25	11.00	11.00	9.75	9.00	8.50	7.25	6.00
9.	19.50	12.00	11.00	11.00	9.75	9.00	8.50	7.25	6.00
12.	18.75	10.75	11.00	11.00	9.75	9.00	8.50	7.25	6.25
15.	17.50	9.25	11.00	11.00	9.50	9.00	8.50	7.25	6.25
18.	15.25	9.00	11.00	11.00	9.50	9.00	8.50	7.25	6.25
21.	13.75	8.50	11.00	11.00	9.50	9.00	8.50	7.25	6.00
24.	11.75	8.00	11.00	11.00	9.50	9.00	8.50	7.25	6.00
27.	10.00	7.75	11.00	11.00	9.50	9.00	8.50	7.25	6.00
30.	9.25	7.25	11.00	10.75	9.50	9.00	8.50	7.25	6.00
33.	8.75	7.00	10.75	10.50	9.50	9.00	8.50	7.00	6.00
36.	8.25	6.75	10.50	10.25	9.50	9.00	8.50	7.00	6.00
39.	7.75	6.50	8.50	9.50	9.50	8.75	8.50	6.75	6.00
42.	7.50	6.25	7.00	8.75	9.50	8.75	8.50	6.75	6.00
45.	7.25	6.00	6.50	8.50	9.25	8.50	8.50	6.50	6.00
48.	7.00	6.00	6.50	7.75	9.00	8.50	8.50	6.50	6.00
51.	6.75	5.75	6.25	7.50	8.75	8.00	8.50	6.50	6.00
54.	6.50	5.50	5.75	7.00	8.50	7.50	7.75	6.25	5.75
57.	6.50	5.50	5.50	6.75	7.00	7.00	7.50	6.00	5.75
60.	6.25	5.50	5.50	6.50	6.75	6.75	7.00	6.00	5.50
63.	6.00	5.50	5.25	6.25	6.50	6.50	6.75	5.75	5.50
66.	6.00	5.50	5.25	6.00	6.25	6.25	6.50	5.50	5.50
69.	5.75	5.25	5.25	5.75	5.75	6.00	6.25	5.50	5.50
72.	5.75	5.25	5.25	5.50	5.75	6.00	6.00	5.50	5.50
75.	5.50	5.25	5.00	5.50	5.50	5.75	5.75	5.50	5.50
78.	5.50	5.00	5.00	5.50	5.50	5.50	5.50	5.50	5.25
81.	5.50	5.00	5.00	5.50	5.50	5.50	5.50	5.25	5.25
84.	5.50	5.00	5.00	5.25	5.25	5.50	5.25	5.00	5.25
87.	5.50	5.00	5.00	5.25	5.00	5.25	5.25	5.00	5.25
90.	5.50	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
93.	5.25	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
96.	5.25	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
99.	5.25	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
102.	5.25	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
105.	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
108.	5.00	5.00	5.00	5.00	5.00	4.75	4.75	5.00	5.00
111.	5.00	5.00	5.00	5.00	5.00	4.75	4.75	5.00	5.00
114.	5.00	5.00	5.00	5.00	5.00	4.75	4.75	5.00	4.75
117.	5.00	5.00	5.00	5.00	5.00	4.50	4.50	5.00	4.75
120.	5.00	5.00	5.00	5.00	5.00	4.50	4.50	5.00	4.75
123.	5.00	5.00	4.75	5.00	5.00	4.50	4.50	5.00	4.75
126.	5.00	5.00	4.75	4.75	5.00	4.50	4.50	5.00	4.75
129.	5.00	5.00	4.75	4.75	5.00	4.50	4.50	4.75	4.75
132.	5.00	5.00	4.75	4.75	5.00	4.50	4.50	4.75	4.75
135.	5.00	5.00	4.50	4.50	5.00	4.50	4.50	4.75	4.75

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LAKE TAHOE 1970  *****TEMPERATURE PROFILES*****
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DEPTH   1/ 6   1/19   1/30   2/10   2/23   2/28   3/10   3/23   4/ 2   4/15   5/ 2   5/25   6/ 9   6/16   7/ 1   7/ 7   7/14   7/20
 (M)
   0.   6.00   5.50   5.50   5.25   5.50   5.25   5.00   5.75   6.50   5.50   9.50  11.50  12.00  12.25  15.50  15.75  18.00  20.00
   3.   6.00   5.50   5.50   5.25   5.50   5.25   5.00   5.50   5.75   5.50   7.75  11.00  11.25  11.50  14.25  15.00  16.75  18.25
   6.   6.00   5.50   5.50   5.25   5.50   5.25   5.00   5.50   5.50   5.50   6.50   9.50  10.50  11.00  13.25  14.00  15.50  16.75
   9.   6.00   5.50   5.50   5.25   5.50   5.25   5.00   5.50   5.25   5.50   6.50   9.50  10.25  10.50  13.00  13.25  14.75  16.00
  12.   6.00   5.50   5.50   5.25   5.50   5.25   5.00   5.50   5.25   5.50   6.50   9.25   9.75  10.00  12.50  12.75  14.00  15.00
  15.   6.00   5.50   5.50   5.25   5.50   5.25   5.00   5.50   5.25   5.50   6.50   9.00   9.25   9.50  12.50  12.50  13.50  13.75
  18.   6.00   5.50   5.50   5.25   5.50   5.25   5.00   5.50   5.25   5.50   6.50   7.75   8.75   9.25  12.25  11.75  12.50  12.25
  21.   6.00   5.50   5.50   5.25   5.50   5.00   5.00   5.50   5.00   5.50   6.25   7.50   8.25   9.00  11.50  10.75  11.50  11.00
  24.   6.00   5.50   5.50   5.25   5.50   5.00   5.00   5.25   5.00   5.50   6.25   7.50   8.00   8.75  10.25   9.50  11.00  10.50
  27.   6.00   5.50   5.50   5.25   5.50   5.00   5.00   5.25   5.00   5.50   6.25   7.50   7.75   8.50   9.75   9.00  10.25   9.75
  30.   6.00   5.50   5.50   5.25   5.50   5.00   5.00   5.25   5.00   5.25   6.25   7.25   7.50   8.50   9.50   8.50   9.00   9.00
  33.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.25   6.00   7.25   7.50   8.25   8.75   8.25   8.75   8.50
  36.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.25   6.00   7.00   7.25   8.00   8.00   8.00   8.25   8.25
  39.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   6.00   7.00   7.00   7.75   7.25   7.75   8.00   8.00
  42.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   6.00   7.00   7.00   7.50   7.00   7.50   7.75   7.75
  45.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   6.00   6.75   6.75   7.50   7.00   7.25   7.50   7.50
  48.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   6.00   6.50   6.50   7.25   6.75   7.00   7.00   7.25
  51.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   6.00   6.50   6.50   7.25   6.75   7.00   7.00   7.25
  54.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.75   6.50   6.25   7.00   6.50   6.75   7.00   7.00
  57.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.75   6.50   6.25   7.00   6.50   6.50   6.75   6.75
  60.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.75   6.25   6.00   7.00   6.25   6.50   6.50   6.75
  63.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.75   6.25   6.00   6.75   6.25   6.50   6.50   6.50
  66.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.75   6.25   6.00   6.50   6.25   6.25   6.50   6.50
  69.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.75   6.00   6.00   6.50   6.25   6.25   6.25   6.50
  72.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.75   6.00   6.00   6.25   6.00   6.00   6.25   6.50
  75.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.50   6.00   5.75   6.00   6.00   6.00   6.00   6.25
  78.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.50   6.00   5.75   6.00   6.00   6.00   6.00   6.25
  81.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.50   5.75   5.75   6.00   6.00   6.00   6.00   6.25
  84.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.50   5.75   5.75   6.00   6.00   6.00   6.00   6.00
  87.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.50   5.75   5.75   6.00   6.00   6.00   6.00   6.00
  90.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.50   5.75   5.50   5.75   5.75   5.75   5.75   6.00
  93.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.25   5.00   5.00   5.50   5.75   5.50   5.75   5.75   5.75   5.75   6.00
  96.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.75   6.00
  99.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 102.   6.00   5.50   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 105.   6.00   5.25   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 108.   5.75   5.25   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 111.   5.75   5.25   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 114.   5.50   5.25   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 117.   5.50   5.25   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 120.   5.50   5.25   5.50   5.00   5.50   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 123.   5.50   5.25   5.50   5.00   5.25   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 126.   5.50   5.25   5.50   5.00   5.25   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 129.   5.50   5.25   5.50   5.00   5.25   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 132.   5.50   5.25   5.50   5.00   5.25   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
 135.   5.50   5.00   5.50   5.00   5.25   5.00   5.00   5.00   5.00   5.00   5.50   5.50   5.50   5.75   5.75   5.75   5.50   6.00
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LAKE TAHOE 1970  *****TEMPERATURE PROFILES*****
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DEPTH  7/24   7/31   8/11   8/17   8/24   9/ 2   9/ 8   9/17   9/23
 (M)
  0.  18.50  17.25  18.25  18.75  18.25  18.00  16.75  15.50  14.00
  3.  17.75  16.75  18.00  18.50  18.00  17.75  16.75  15.50  14.00
  6.  17.00  16.00  18.00  18.25  17.75  17.50  16.75  15.25  13.75
  9.  16.50  16.00  17.50  17.75  17.50  17.50  16.75  15.25  13.75
 12.  15.75  15.75  16.50  16.50  17.00  17.00  15.75  15.00  13.75
 15.  14.50  15.50  15.25  14.50  16.00  16.50  15.00  15.00  13.75
 18.  13.75  14.75  13.25  12.50  13.75  14.00  14.50  14.75  13.50
 21.  13.00  13.50  11.50  10.75  12.00  12.25  13.75  14.50  13.25
 24.  11.75  11.25  10.50  10.00  11.25  11.75  12.75  13.75  12.25
 27.  11.00  10.00   9.50   9.00  10.25  11.00  12.00  12.50  11.00
 30.  10.50   8.75   8.75   8.25   9.50  10.00  11.50  10.50   9.50
 33.  10.00   8.25   8.25   7.75   8.75   9.00  10.50   9.50   8.50
 36.   9.25   8.00   8.00   7.25   8.00   8.00   9.50   9.00   7.75
 39.   8.50   7.50   7.50   7.00   7.25   7.50   8.75   8.00   7.25
 42.   8.25   7.25   7.25   7.00   6.75   7.25   8.00   7.50   7.00
 45.   7.75   7.25   7.00   6.75   6.50   7.00   7.50   7.00   6.75
 48.   7.50   7.00   7.00   6.75   6.00   6.75   7.00   6.75   6.50
 51.   7.00   7.00   6.75   6.50   5.75   6.50   6.75   6.50   6.25
 54.   7.00   7.00   6.50   6.25   5.75   6.25   6.50   6.25   6.25
 57.   6.75   6.75   6.50   6.00   5.50   6.00   6.50   6.00   6.00
 60.   6.50   6.75   6.50   5.75   5.50   6.00   6.50   6.00   5.75
 63.   6.50   6.50   6.50   5.75   5.25   5.75   6.25   6.00   5.75
 66.   6.50   6.50   6.50   5.75   5.25   5.75   6.00   5.75   5.50
 69.   6.25   6.50   6.25   5.50   5.00   5.75   6.00   5.50   5.50
 72.   6.25   6.25   6.25   5.50   5.00   5.75   6.00   5.50   5.50
 75.   6.00   6.25   6.25   5.50   5.00   5.50   5.75   5.50   5.50
 78.   6.00   6.00   6.00   5.50   4.75   5.50   5.75   5.50   5.25
 81.   6.00   6.00   6.00   5.50   4.75   5.50   5.50   5.50   5.25
 84.   6.00   6.00   6.00   5.25   4.75   5.50   5.50   5.50   5.25
 87.   6.00   6.00   6.00   5.25   4.50   5.50   5.50   5.50   5.25
 90.   6.00   6.00   6.00   5.25   4.50   5.50   5.50   5.50   5.25
 93.   5.75   5.75   6.00   5.00   4.50   5.25   5.50   5.50   5.25
 96.   5.75   5.75   5.75   5.00   4.50   5.25   5.50   5.50   5.00
 99.   5.75   5.75   5.75   5.00   4.50   5.25   5.25   5.50   5.00
102.   5.75   5.75   5.75   5.00   4.50   5.25   5.25   5.50   5.00
105.   5.75   5.75   5.75   5.00   4.50   5.00   5.25   5.50   5.00
108.   5.75   5.75   5.75   5.00   4.50   5.00   5.25   5.25   5.00
111.   5.75   5.75   5.75   5.00   4.50   5.00   5.00   5.25   5.00
114.   5.75   5.75   5.50   5.00   4.50   5.00   5.00   5.25   5.00
117.   5.75   5.75   5.50   5.00   4.50   5.00   5.00   5.25   5.00
120.   5.75   5.75   5.50   5.00   4.50   5.00   5.00   5.00   5.00
123.   5.75   5.75   5.50   5.00   4.50   5.00   5.00   5.00   5.00
126.   5.75   5.75   5.50   5.00   4.50   5.00   5.00   5.00   5.00
129.   5.75   5.75   5.50   5.00   4.25   5.00   5.00   5.00   5.00
132.   5.75   5.75   5.50   5.00   4.25   5.00   5.00   5.00   5.00
135.   5.75   5.75   5.50   5.00   4.25   5.00   5.00   5.00   4.75
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APPENDIX B

LAKE TAHOE PRIMARY PRODUCTIVITY-DEPTH PROFILES

Primary productivity (mg $C \cdot m^{-3} \cdot hr^{-1}$) vs. sampling depth at the index station of Lake Tahoe, 1967-1971. Total (mg $C \cdot m^{-3}$) and average (mg $C \cdot m^{-3}$) productivity per hour of incubation and per day, and total efficiency per calorie of light are also listed.

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LAKE TAHOE 1967  *****PRIMARY PRODUCTIVITY*****
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MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH  7/28     DEPTH  8/ 2     DEPTH  8/ 9     DEPTH  8/14     DEPTH  8/25     DEPTH  9/ 2     DEPTH  9/ 7     DEPTH  9/14     DEPTH  9/21
 (M)             (M)             (M)             (M)             (M)             (M)             (M)             (M)             (M)
   0.   0.14       0.   0.32       0.   0.22       0.   0.23       0.   0.27       0.   0.34       0.   0.27       0.   0.24       0.   0.09
   8.   0.64       3.   0.66      12.   0.27       7.   0.59       7.   0.52       5.   0.50       4.   0.55       3.   0.43       5.   0.47
  15.   0.29      10.   0.67      17.   0.29      12.   0.50      12.   0.72      10.   0.52       8.   0.58       5.   0.56      12.   0.60
  25.   0.38      20.   0.22      25.   0.17      22.   0.27      22.   0.16      24.   0.20      17.   0.19       8.   0.61      24.   0.27
  35.   0.25      35.   0.13      40.   0.32      37.   0.21      37.   0.09      38.   0.14      31.   0.22      11.   0.68      40.   0.26
  50.   0.42      61.   0.41      50.   0.41      50.   0.31      50.   0.07      50.   0.18      43.   0.28      15.   0.64      52.   0.24
  70.   0.34      70.   0.29      70.   0.25      80.   0.18      80.   0.02      70.   0.10      71.   0.43      20.   0.37      80.   0.06
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******      23.   0.26     **** ******
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******      27.   0.21     **** ******
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******      38.   0.44     **** ******
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******      50.   0.46     **** ******
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******      57.   0.32     **** ******
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******      72.   0.15     **** ******
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******      82.   0.16     **** ******

TOTAL MG PER SQUARE METER
      25.57           23.45           20.26           23.82           14.37           16.92           23.08           29.54           21.65
AVERAGE MG PER CUBIC METER
       0.37            0.33            0.29            0.30            0.18            0.24            0.33            0.36            0.27
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER.DAY
     ******          236.42          166.92          213.42          ******          193.34          169.72          222.17          125.18
AVERAGE MG C/CUBIC METER.DAY
     ******            3.46            2.36            2.67          ******            2.76            2.39            2.71            1.56
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
     ******            0.64            0.47            0.60          ******            0.85            0.59            0.75            0.66


DEPTH  9/28     DEPTH 10/ 5     DEPTH 10/11     DEPTH 10/18     DEPTH 10/26     DEPTH 11/ 1     DEPTH 11/ 8     DEPTH 11/15     DEPTH 12/ 1
 (M)             (M)             (M)             (M)             (M)             (M)             (M)             (M)             (M)
   0.   0.23       0.   0.12       0.   0.19       0.   0.16       0.   0.02       0.  -0.01       0.   0.25       0.   0.23       0.   0.06
   7.   0.38       5.   0.11       5.   0.39       5.   0.16       5.   0.22       2.   0.05       2.   0.20       2.   0.23       2.   0.12
  15.   0.20      10.   0.23      10.   0.32      10.   0.23      10.   0.16       5.   0.15       5.   0.23       5.   0.21       5.   0.11
  30.   0.17      15.   0.22      15.   0.24      15.   0.26      15.   0.12      10.   0.21      10.   0.31      10.   0.30      10.   0.18
  50.   0.11      20.   0.27      20.   0.29      20.   0.23      20.   0.36      15.   0.28      15.   0.30      15.   0.30      15.   0.28
  62.   0.06      30.   0.44      30.   0.16      30.   0.14      30.   0.30      20.   0.34      20.   0.30      20.   0.30      20.   0.27
  89.   0.03      40.   0.42      40.   0.57      40.   0.29      40.   0.19      30.   0.30      30.   0.25      30.   0.21      30.   0.33
 **** ******      50.   0.21      50.   0.42      50.   0.37      50.   0.27      40.   0.27      40.   0.26      40.   0.18      40.   0.26
 **** ******      70.   0.11      70.   0.01      70.   0.18      70.   0.18      50.   0.34      50.   0.31      50.   0.18      50.   0.21
 **** ******      90.   0.10      90.  -0.12      90.   0.07      90.   0.07      60.   0.31      60.   0.19      60.   0.15      60.   0.14
 **** ******     **** ******     **** ******     **** ******     **** ******      75.   0.14      75.   0.17      75.   0.08      75.   0.04
 **** ******     **** ******     **** ******     **** ******     **** ******      90.   0.03      90.   0.03      90.   0.05      90.   0.04
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******
 **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******     **** ******

TOTAL MG PER SQUARE METER
      11.40           19.86           20.09           19.53           20.56           21.00           17.58           16.03           15.63
AVERAGE MG PER CUBIC METER
       0.13            0.22            0.22            0.22            0.23            0.23            0.22            0.18            0.18
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER.DAY
     149.33          132.94          ******          132.81          133.69          142.24          109.89          111.32          137.08
AVERAGE MG C/CUBIC METER.DAY
       1.68            1.46          ******            1.48            1.49            1.58            1.22            1.24            1.52
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
       0.76            0.57          ******            0.77            0.81            0.86            0.79            1.17            0.80
  LAKE TAHOE 1967  *****PRIMARY PRODUCTIVITY*****
  ***********************************************
  MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH 12/ 8
 (M)
  0.    0.05
  2.    0.04
  5.    0.07
 10.    0.09
 15.    0.16
 20.    0.21
 30.    0.18
 40.    0.21
 50.    0.18
 60.    0.11
**** ******
**** ******
**** ******
**** ******

TOTAL MG PER SQUARE METER
        9.42
AVERAGE MG PER CUBIC METER
        0.16
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER.DAY
       66.80
AVERAGE MG C/CUBIC METER.DAY
        1.11
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        0.75
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LAKE TAHOE 1968  *****PRIMARY PRODUCTIVITY*****
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MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH   1/ 2     1/17     1/24     2/ 6     2/14     2/20     2/24     3/ 6     3/13     3/20     3/26     4/ 2     4/11     4/18     4/25
 (M)
  0.     0.15     0.06    -0.02     0.02     0.04     0.03     0.05     0.03     0.03    -0.04     0.04     0.07     0.03     0.02     0.00
  2. *******     0.02     0.03     0.04     0.05     0.04     0.03     0.04 *******     0.02     0.03     0.10    -0.00     0.02    -0.06
  5.     0.18     0.03     0.06     0.08     0.09     0.06     0.02     0.06     0.06     0.02     0.02     0.13     0.02     0.05     0.02
 10.     0.31     0.06     0.09     0.07     0.16     0.10     0.06     0.07     0.08     0.07     0.07     0.17     0.05     0.06     0.05
 15.     0.39     0.08     0.06     0.10     0.15     0.15     0.08     0.19     0.13     0.11     0.11     0.21     0.10     0.13     0.08
 20.     0.48     0.19     0.22     0.15     0.27     0.26     0.15     0.25     0.16     0.21     0.18     0.25     0.12     0.19    -0.23
 30.     0.45     0.27     0.33     0.24     0.37     0.37     0.26     0.37     0.20     0.37     0.37     0.35     0.20     0.29     0.10
 40.     0.34     0.24     0.31     0.29     0.32     0.39     0.26     0.55     0.23     0.42     0.51     0.32     0.26     0.31     0.37
 50.     0.22     0.21     0.32     0.32     0.30     0.37     0.29     0.65     0.20     0.41     0.50     0.39     0.34     0.25     0.29
 60.     0.12     0.23     0.29     0.26     0.25     0.31     0.28     0.51     0.20     0.36     0.39     0.32     0.50     0.24     0.41
 75.     0.07     0.12     0.17     0.23     0.15     0.17     0.21     0.35     0.12     0.13     0.28     0.17     0.27     0.17     0.24
 90.     0.02     0.06     0.10     0.13     0.08     0.10     0.16     0.17     0.09     0.11     0.13     0.08     0.12     0.02    -0.92
105. ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* *******
120. ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* *******

TOTAL MG PER SQUARE METER
        21.15    14.61    19.17    18.40    19.90    22.02    18.00    32.10    13.65    21.82    26.32    22.42    22.06    16.83     8.07
AVERAGE MG PER CUBIC METER
         0.24     0.16     0.21     0.20     0.22     0.24     0.20     0.36     0.15     0.24     0.29     0.25     0.25     0.19     0.09
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
       169.21 ******* *******   116.67   135.49   159.83   113.51   178.22   156.62   105.66   213.80   203.05   264.25   134.64    42.09
AVERAGE MG C/CUBIC METER,DAY
         1.88 ******* *******     1.30     1.51     1.70     1.26     1.98     1.74     1.84     2.38     2.26     2.94     1.50     0.87
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
         2.60 ******* *******     0.97     1.64     1.25     0.53     0.78     1.76     0.69     0.77     1.28     0.99     0.42     0.15


DEPTH   5/ 1     5/ 9     5/16     5/22     5/29     6/ 5     6/12     6/19     6/26     7/ 4     7/11     7/17     7/24     7/31     8/ 7
 (M)
  0.     0.03     0.11    -0.01     0.01     0.02     0.09     0.03     0.12     0.20     0.21     0.17     0.17     0.19     0.48     0.17
  2.     0.03     0.12     0.04     0.01     0.02     0.11     0.04     0.13     0.17     0.16     0.22     0.11     0.22     0.47     0.22
  5. *******     0.08     0.01     0.02     0.04     0.14     0.07     0.17     0.24     0.16     0.21     0.18     0.31     0.63     0.32
 10.     0.12     0.13     0.05     0.03     0.05     0.15     0.10     0.12     0.23     0.21     0.24     0.15     0.70     0.53     0.49
 15.     0.11     1.29     0.08     0.05     0.09     0.12     0.12     0.11     0.15     0.21     0.24     0.31     0.68     0.25     0.34
 20.     0.19     0.05     0.12     0.07     0.11     0.13     0.15     0.12     0.15     0.17     0.22     0.29     0.35     0.17     0.28
 30.     0.27     0.30     0.18     0.13     0.13     0.15     0.15     0.16     0.18     0.12     0.12     0.15     0.23     0.10 *******
 40.    -0.03     0.25     0.19     0.25     0.12     0.11     0.16     0.13     0.12     0.12     0.19     0.11     0.10     0.05 *******
 50.     0.10     0.35    -0.04     0.28     0.21     0.10     0.20     0.12     0.13     0.11     0.19     0.10     0.08     0.04 *******
 60.     0.22     0.25     0.19     0.29     0.27     0.08     0.15     0.15     0.20     0.12     0.18     0.09     0.30     0.03 *******
 75.     0.27     0.18     0.19     0.22     0.20     0.05     0.13     0.24     0.26     0.14     0.17     0.13     0.05     0.01 *******
 90.     0.03     0.06     0.10     0.14     0.12     0.05     0.08     0.19     0.14     0.14     0.14     0.03     0.02     0.02 *******
105.     0.02     0.03     0.04     0.10     0.05     0.01     0.05     0.11     0.08    -0.03     0.04     0.01     0.00     0.01 *******
120.     0.00 ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* *******

TOTAL MG PER SQUARE METER
        13.86    24.10    12.00    17.43    14.90     9.41    13.22    16.46    18.17    13.46    17.69    12.91    20.90    12.08     6.89
AVERAGE MG PER CUBIC METER
         0.12     0.23     0.11     0.17     0.14     0.09     0.13     0.16     0.17     0.13     0.17     0.12     0.20     0.12     0.34
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
       107.85   201.17   136.70   148.96   167.57    87.56   120.93   133.20   159.45   101.74   158.08   108.62   172.44   204.31    55.74
AVERAGE MG C/CUBIC METER,DAY
         0.90     1.92     1.30     1.42     1.60     0.83     1.15     1.27     1.52     0.97     1.51     1.04     1.64     1.95     2.79
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
         0.34     0.62     0.39     0.54     0.48     0.47     0.38     0.38     0.46     0.33     0.46     0.31     0.51     2.20     0.20
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LAKE TAHOE 1968  *****PRIMARY PRODUCTIVITY*****
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MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH   8/ 7    8/12    8/21    8/28    9/ 2    9/11    9/17    9/26   10/15   10/19   10/27   11/ 2   12/ 1   12/ 7
 (M)
  0. *******    0.15    0.04    0.01    0.19    0.17    0.07    0.08    0.08    0.11    0.13    0.20    0.20    0.09
  2. *******    0.13    0.08    0.03    0.15    0.21    0.13    0.10    0.08    0.12    0.11    0.23    0.18    0.10
  5. *******    0.38    0.11    0.07    0.16    0.27    0.18    0.15    0.12    0.15    0.15    0.28    0.19    0.14
 10. *******    0.56    0.09    0.03    0.21    0.43    0.27    0.24    0.16    0.23    0.23    0.27    0.20    0.18
 15. *******    0.04    0.17    0.08    0.18    0.42    0.28    0.30    0.16    0.24    0.25    0.29    0.21    0.23
 20. *******    0.21    0.08    0.16    0.17    0.48    0.32    0.28    0.24    0.26    0.28    0.24    0.22    0.29
 30.    0.15    0.07    0.15    0.13    0.14    0.15    0.19    0.20    0.24    0.24    0.25    0.20    0.16    0.31
 40.    0.12    0.12    0.10    0.15    0.10    0.14    0.17    0.14    0.21    0.15    0.18    0.19    0.16    0.28
 50.    0.10    0.11    0.08    0.16    0.16    0.18    0.17    0.18    0.13    0.12    0.16    0.14    0.10    0.26
 60.    0.05    0.15    0.08    0.22    0.14    0.14    0.14    0.13    0.10    0.11    0.13    0.10    0.08    0.15
 75.    0.08    0.07    0.04    0.13    0.11    0.08    0.10    0.08    0.06    0.08    0.07    0.06    0.03    0.11
 90.    0.04    0.07   -0.[illegible]    0.10    0.06    0.06    0.05    0.04    0.04    0.05    0.04   -0.00    0.01    0.04
105. *******    0.05   -0.04    0.03    0.02    0.04    0.03    0.03    0.02    0.02    0.03    0.00    0.00    0.01
120. ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* *******

TOTAL MG PER SQUARE METER
        5.16   13.84    6.56   12.80   12.93   18.50   15.78   14.56   12.90   13.80   14.90   14.00   10.76   17.80
AVERAGE MG PER CUBIC METER
        0.09    0.13    0.06    0.12    0.12    0.18    0.15    0.14    0.12    0.13    0.14    0.13    0.10    0.17
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
       44.10  121.37   47.56   94.40   94.88  127.94  110.82  105.70   84.15  117.75   93.94   86.78   58.39  100.44
AVERAGE MG C/CUBIC METER,DAY
        0.73    1.16    0.45    0.90    0.92    1.22    1.06    1.01    0.82    1.12    0.89    0.83    0.56    0.96
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        0.16    0.37    0.27    0.36    0.34    0.50    0.46    0.50    0.47    0.62    0.62    1.40    0.88    0.94
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LAKE TAHOE 1969  *****PRIMARY PRODUCTIVITY*****
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MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH   1/16    2/ 1    2/15    3/ 2    3/15    3/30    4/13    4/25    5/ 9    5/23    6/ 7    6/20    7/ 1    7/ 8    7/15
 (M)
  0.    0.14    0.06    0.25    0.03    0.01    0.01    0.01    0.02    0.11    0.07    0.17    0.12    0.08    0.07    0.15
  2.    0.11    0.07    0.28    0.03    0.00    0.01    0.01    0.01    0.05    0.06    0.21    0.18    0.18    0.26    0.18
  5.    0.12    0.08    0.31    0.06   -0.00    0.02    0.04    0.03    0.10    0.11    0.38    0.22    0.15    0.30    0.28
 10.    0.20    0.13    0.40    0.11    0.08    0.05    0.10    0.07    0.12    0.19    0.33    0.36    0.19    0.40    0.29
 15.    0.33    0.21    0.40    0.21    0.09    0.10    0.23    0.17    0.13    0.33    0.28    0.23    0.15    0.38    0.22
 20.    0.44    0.19    0.40    0.27    0.15    0.15    0.27    0.28    0.22    0.30    0.27    0.11    0.17    0.22    0.22
 30.    0.52    0.25    0.32    0.39    0.34    0.30    0.44    0.51    0.32    0.31    0.17    0.08    0.15    0.12    0.13
 40.    0.47    0.29    0.22    0.39    0.43    0.60    0.50    0.59    0.40    0.32    0.16    0.31    0.11    0.15    0.08
 50.    0.32    0.20    0.16    0.35    0.54    0.61    0.50    0.46    0.55    0.40    0.12    0.19    0.02    0.09    0.13
 60.    0.18    0.16    0.09    0.25    0.44    0.51    0.42    0.38    0.41    0.28    0.20    0.23    0.20    0.12    0.19
 75.    0.10    0.09    0.00    0.07    0.27    0.33    0.23    0.22    0.09    0.12    0.12    0.12    0.14    0.12    0.12
 90.    0.03    0.07    0.01    0.18    0.12    0.14    0.10    0.08    0.10    0.07    0.04    0.05    0.06    0.03    0.07
105.    0.02    0.03    0.02    0.07    0.09    0.09    0.07    0.04    0.11    0.05    0.02    0.12    0.02    0.02    0.02

TOTAL MG PER SQUARE METER
       24.23   15.72   18.47   22.65   27.22   31.17   28.98   28.64   24.94   22.56   16.75   17.45   12.40   14.75   14.69
AVERAGE MG PER CUBIC METER
        0.23    0.15    0.18    0.22    0.26    0.30    0.28    0.27    0.24    0.21    0.16    0.17    0.12    0.14    0.14
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
      138.81  118.09  133.62  124.60  198.16  242.06  211.91  265.74  195.93  195.51  134.26  137.65  102.25  162.34  122.26
AVERAGE MG C/CUBIC METER,DAY
        1.28    1.12    1.27    1.19    1.86    2.31    2.02    2.53    1.87    1.86    1.28    1.31    0.97    1.55    1.16
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        1.17    1.21    4.31    0.94    0.80    0.88    0.81    0.83    0.66    0.57    0.43    0.43    0.29    0.67    0.36


DEPTH   7/22    7/24    7/30    8/ 5    8/14    8/20    8/26    9/ 3    9/ 9    9/15    9/23   10/10   10/22   10/28   11/12
 (M)
  0.    0.08    0.14    0.10    0.08    0.21    0.06    0.09    0.10    0.07    0.15    0.11    0.06   -0.00    0.06    0.04
  2.    0.22    0.25    0.11    0.22    0.10    0.16    0.13    0.11    0.19    0.27 *******    0.10    0.07    0.05    0.07
  5.    0.29    0.36    0.21    0.31    0.19    0.24    0.21    0.19    0.19    0.30    0.19    0.13    0.17    0.08    0.06
 10.    0.39    0.30    0.28    0.45    0.27    0.29    0.25    0.14    0.44    0.42    0.18    0.20    0.22    0.16    0.17
 15.    0.28    0.29    0.26    0.33    0.24    0.24    0.29    0.11    0.42    0.29    0.28    0.13    0.27    0.19    0.19
 20.    0.21    0.20    0.16    0.24    0.19    0.22    0.38    0.28    0.24    0.24    0.20    0.14    0.23    0.25    0.20
 30.    0.12    0.10    0.13    0.14    0.22    0.11    0.11    0.19    0.22    0.13    0.09    0.16    0.27    0.17    0.24
 40.    0.10    0.11    0.08    0.12    0.19    0.16    0.20    0.12    0.13    0.18    0.19    0.26    0.30    0.22    0.16
 50.    0.10    0.11    0.17    0.11    0.19    0.14    0.17   -0.01    0.20    0.15    0.15    0.18    0.31    0.06    0.15
 60.    0.16    0.16    0.12    0.11    0.13    0.12    0.12    0.08    0.10    0.11    0.12    0.13    0.22    0.14    0.14
 75.    0.07    0.08    0.11    0.05    0.17    0.13    0.11    0.02    0.06    0.08    0.08    0.11    0.13    0.08    0.08
 90.    0.06    0.06 *******    0.06    0.09    0.10    0.07    0.03    0.01    0.05    0.06    0.06    0.11    0.03    0.03
105.    0.05    0.01 *******    0.04    0.05    0.08    0.07 *******    0.03    0.04    0.03    0.03    0.02    0.00    0.00

TOTAL MG PER SQUARE METER
       14.38   14.13   11.13   14.47   17.26   15.31   16.40    9.15   15.42   15.67   13.15   13.87   20.30   12.15   12.88
AVERAGE MG PER CUBIC METER
        0.14    0.13    0.15    0.14    0.16    0.15    0.16    0.10    0.15    0.15    0.13    0.13    0.19    0.12    0.12
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
      124.95  113.84   85.48  112.39  127.62  130.27  116.49  222.39  104.77  120.96   93.10   92.11  122.37   74.86   77.45
AVERAGE MG C/CUBIC METER,DAY
        1.19    1.08    1.14    1.07    1.22    1.24    1.11    2.47    1.00    1.15    0.89    0.88    1.17    0.71    0.74
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        0.39    0.35    0.26    0.35    0.43    0.45    0.38    0.82    0.42    0.49    0.38    0.48    0.69    0.46    0.55
  LAKE TAHOE 1969  *****PRIMARY PRODUCTIVITY*****
  ************************************************
  MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH  11/23   12/ 5   12/16   12/26
 (M)
  0.     0.11    0.05    0.03   -0.01
  2.     0.08    0.07    0.05    0.08
  5.     0.09    0.11    0.10    0.11
 10.     0.21    0.24    0.14    0.23
 15.     0.24    0.30    0.14    0.25
 20.     0.30    0.39    0.31    0.16
 30.     0.35    0.33    0.26    0.24
 40.     0.17    0.29    0.21    0.18
 50.     0.06    0.21    0.16    0.14
 60.     0.17    0.19    0.14    0.08
 75.     0.12    0.03    0.05    0.04
 90. *******     0.02    0.02    0.00
105.     0.04    0.01    0.02    0.01

TOTAL MG PER SQUARE METER
        16.27   17.65   13.59   11.52
AVERAGE MG PER CUBIC METER
         0.15    0.17    0.13    0.11
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
       114.05  107.72   81.24   76.78
AVERAGE MG C/CUBIC METER,DAY
         1.09    1.03    0.77    0.73
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
         0.77    0.80    0.63    0.55
```

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LAKE TAHOE 1970  *****PRIMARY PRODUCTIVITY******
**************************************************
MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH    1/ 6    1/19    1/30    2/10    2/23    2/26    3/10    3/23    4/ 2    4/15    5/ 2    5/13    5/25    6/16    7/ 1
 (M)
  0.     0.05    0.04    0.07    0.15    0.01    0.04    0.00   -0.00    0.01   -0.00   -0.00    0.04    0.03    0.08    0.00
  2.     0.05    0.08    0.09    0.17    0.02    0.06    0.01    0.02   -0.01    0.00    0.04    0.00    0.01    0.11    0.09
  5.     0.11    0.12    0.07    0.22    0.03    0.09    0.04    0.01    0.04   -0.01    0.02    0.06    0.05    0.02    0.00
 10.     0.11    0.17    0.15    0.27    0.09    0.13    0.04    0.04    0.05    0.02    0.02    0.05    0.12    0.14    0.15
 15.     0.19    0.20    0.24    0.28    0.12    0.17    0.08    0.08    0.10    0.04    0.05    0.05    0.17    0.19    0.27
 20.     0.27    0.26    0.24    0.35    0.15    0.19    0.13    0.13    0.15    0.10    0.04    0.20    0.27    0.20    0.21
 30.     0.24    0.28    0.33    0.30    0.30    0.18    0.18    0.25    0.23    0.16    0.06    0.16    0.43    0.21    0.21
 40.     0.22    0.21    0.28    0.24    0.27    0.22    0.26    0.29    0.26    0.20    0.16    0.26    0.42    0.19    0.25
 50.     0.17    0.13    0.22    0.15    0.27    0.19    0.24    0.26    0.23    0.27    0.17    0.26    0.30    0.16    0.13
 60.     0.10    0.09    0.15    0.09    0.27    0.15    0.19    0.24    0.10    0.19    0.36    0.26    0.35    0.18    0.23
 75.     0.10    0.04    0.05    0.03    0.13    0.08    0.11    0.13    0.06    0.12    0.14    0.25    0.44    0.16    0.10
 90.     0.05   -0.00    0.08    0.02    0.05    0.02    0.06    0.08    0.04    0.07    0.10    0.10    0.21    0.09    0.13
105.     0.04    0.01   -0.01    0.02    0.03    0.01    0.04    0.01    0.02    0.03    0.06    0.15    0.11    0.03    0.07
125. ******* ******* ******* ******* ******* ******* ******* *******    0.00    0.00    0.04 *******    0.05    0.08 *******
150. ******* ******* ******* ******* ******* ******* ******* *******    0.01    0.00 ******* *******   -0.00    0.03    0.03

TOTAL MG PER SQUARE METER
        14.23   12.39   15.84   15.81   17.13   12.08   13.01   16.11   13.57   13.13   14.46   20.17   31.72   16.92   20.47
AVERAGE MG PER CUBIC METER
         0.14    0.12    0.15    0.15    0.16    0.12    0.13    0.15    0.09    0.09    0.12    0.19    0.21    0.11    0.14
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
       112.76   89.87  118.08  139.09  118.94   91.56   78.76  119.38  128.70   99.38  115.86  168.02  258.20  130.63  163.50
AVERAGE MG C/CUBIC METER,DAY
         1.07    0.87    1.11    1.24    1.11    0.76    0.71    1.14    0.86    0.66    0.93    1.59    1.72    0.87    1.09
TOTAL EFFICIENCY (PER CALORIE OF LIGHT) (X .0001)
         0.96    1.01    0.75    1.70    0.87    1.08    0.43    0.44    0.65    0.36    0.38    0.55    0.00    0.43    0.89


DEPTH    7/ 7    7/14    7/21    7/28    7/31    8/11    8/17    8/24    9/ 2    9/ 8    9/16    9/23    10/ 2   10/14   11/10
 (M)
  0.     0.07    0.15    0.18    0.23    0.25    0.40    0.26    0.20    0.06    0.14    0.21    0.26    0.16    0.12    0.08
  2.     0.08    0.23    0.29    0.39    0.26    0.38    0.36    0.25    0.32    0.24    0.38    0.31    0.23    0.29    0.12
  5.     0.11    0.26    0.18    0.38    0.40    0.43    0.53    0.25    0.29    0.29    0.20    0.27    0.27    0.21    0.15
 10.     0.08    0.27    0.40    0.43    0.50    0.56    0.55    0.37    0.40    0.40    0.46    0.37    0.36    0.10    0.29
 15.     0.10    0.24    0.27    0.38    0.51    0.46    0.34    0.24    0.20    0.31    0.42    0.42    0.29    0.31    0.40
 20.     0.07    0.17    0.12    0.31    0.49    0.33    0.27    0.30    0.24    0.32    0.40    0.45    0.80 *******    0.53
 30.     0.04    0.14    0.15    0.09    0.17    0.15    0.16    0.20    0.09    0.22    0.25    0.19    0.39    0.41    0.51
 40.     0.06    0.11    0.10    0.14    0.18    0.11    0.11    0.18    0.17    0.15    0.25    0.26    0.08    0.27    0.43
 50.     0.08    0.10    0.12    0.15    0.23    0.16    0.10    0.18    0.08    0.15    0.27    0.22    0.24    0.33    0.30
 60.     0.09    0.17    0.13    0.12    0.19    0.18    0.15    0.16    0.15    0.11    0.29    0.20    0.20    0.23    0.22
 75.     0.22    0.22    0.13    0.27    0.21    0.15    0.17    0.15    0.05    0.12    0.20    0.07    0.35    0.15    0.02
 90.     0.06    0.20    0.11    0.15    0.14    0.14    0.13    0.14    0.13    0.13    0.11    0.05    0.07 *******    0.11
105.     0.04    0.08    0.09    0.10    0.12    0.19    0.11    0.10    0.10    0.08    0.09    0.03    0.03    0.10    0.08
125. *******    0.08    0.02   -0.00 ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* *******
150.     0.02 ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* ******* *******

TOTAL MG PER SQUARE METER
        10.70   19.46   17.41   22.00   24.27   22.75   20.66   19.78   14.42   18.74   26.26   20.42   23.46   24.21   26.07
AVERAGE MG PER CUBIC METER
         0.07    0.10    0.14    0.18    0.24    0.22    0.20    0.19    0.16    0.18    0.25    0.19    0.22    0.23    0.20
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
        85.44  101.97  134.60  179.09  217.78  171.70  165.68  149.59  125.66  132.28  199.97  147.32  168.22  175.96  174.07
AVERAGE MG C/CUBIC METER,DAY
         0.57    1.30    1.08    1.43    2.07    1.44    1.58    1.42    1.20    1.26    1.90    1.40    1.60    1.68    1.86
TOTAL EFFICIENCY (PER CALORIE OF LIGHT) (X .0001)
         0.28    0.52    0.47    0.59    0.69    0.59    0.64    0.50    0.44    0.48    0.76    0.58    0.74    0.85    1.16
  LAKE TAHOE 1970  *****PRIMARY PRODUCTIVITY*****
  **********************************************
  MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH  12/ 6   12/22
 (M)
  0.     0.14    0.07
  2.     0.50    0.06
  5.     0.32    0.09
 10.     0.21    0.18
 15.     0.50    0.26
 20.     0.21    0.30
 30.     0.26    0.40
 40.     0.38    0.49
 50.     0.19    0.29
 60.     0.14    0.09
 75.     0.09    0.10
 90.    -0.07    0.04
105.     0.01    0.04
125. ******* *******
150. ******* *******

TOTAL MG PER SQUARE METER
       18.16   20.26
AVERAGE MG PER CUBIC METER
        0.17    0.19
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
      147.84  121.54
AVERAGE MG C/CUBIC METER,DAY
        1.41    1.16
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        1.26    0.95
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LAKE TAHOE 1971  *****PRIMARY PRODUCTIVITY******
*************************************************
MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH   1/ 8    1/21    2/ 3    2/12    2/22    3/ 7    3/17    4/ 2    4/13    4/23    5/ 5    5/19    6/ 1    6/14    6/25
 (M)
  0.    0.10    0.03    0.05    0.03    0.07    0.01   -0.00   -0.01    0.01   -0.02    0.04    0.01    0.12    0.11    0.07
  2.    0.29    0.04    0.04    0.04    0.05    0.03    0.01    0.02    0.01    0.06    0.01    0.02    0.14    0.10    0.15
  5.    0.22    0.10    0.06    0.06    0.09    0.03    0.02    0.01    0.01    0.01    0.02    0.02    0.18    0.18    0.21
 10.    0.24    0.12    0.13    0.12    0.14    0.09    0.03    0.02    0.07    0.05    0.05    0.03    0.28    0.34    0.23
 15.    0.42    0.17    0.17    0.15    0.18    0.09    0.05    0.07    0.09    0.09    0.04    0.10    0.36    0.27    0.28
 20.    0.37    0.10    0.25    0.22    0.27    0.14    0.12    0.10    0.17    0.13    0.08    0.12    0.42    0.20    0.24
 30.    0.47    0.24    0.35    0.30    0.41    0.23    0.24    0.18    0.19    0.21    0.15    0.15    0.50    0.40    0.20
 40.    0.41    0.40    0.38    0.39    0.45    0.41    0.29    0.23    0.25    0.22    0.20    0.21 *******    0.39    0.27
 50.    0.28    0.31    0.38    0.39    0.33    0.50    0.38    0.31    0.31    0.31    0.24    0.18    0.32    0.34    0.21
 60.    0.19    0.23    0.23    0.33    0.20    0.43    0.34    0.30    0.30    0.29    0.19    0.21    0.22    0.28    0.18
 75.    0.11    0.12    0.14    0.19    0.16    0.23    0.30    0.27    0.25    0.25    0.12    0.18    0.09    0.13    0.16
 90.    0.04    0.09    0.07    0.11    0.07    0.17    0.17    0.17    0.24    0.17    0.05    0.06    0.07    0.03    0.06
105.    0.02    0.06    0.05    0.04    0.02    0.13    0.10    0.08    0.07    0.09    0.06    0.02   -0.03    0.08    0.07

TOTAL MG PER SQUARE METER
       24.19   20.10   21.25   23.05   22.18   26.06   22.53   19.45   21.28   19.81   12.62   12.84   24.80   23.01   18.34
AVERAGE MG PER CUBIC METER
        0.23    0.19    0.20    0.22    0.21    0.25    0.21    0.19    0.20    0.19    0.12    0.12    0.24    0.22    0.17
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
      133.05  124.87  137.49  133.54  170.35  164.67  160.08  187.82  145.07  158.11  103.34  105.27  249.68  182.65  172.07
AVERAGE MG C/CUBIC METER,DAY
        1.27    1.19    1.31    1.86    1.62    1.57    1.52    1.41    1.38    1.47    0.98    1.00    2.38    1.74    1.64
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        1.61    0.88    0.92    0.88    1.62    0.83    0.82    0.62    0.77    0.55    0.47    0.34    1.37    0.58    0.56


DEPTH   7/ 1    7/ 8    7/14    7/22    8/ 3    8/11    8/17    8/24    9/ 2    9/ 9    9/16    9/23   10/ 5   10/30   11/ 9
 (M)
  0.    0.13    0.19    0.32    0.19    0.58    0.63    0.27    0.88    0.16    0.07    0.33    0.21    0.15    0.17    0.04
  2.    0.13    0.40    0.90    0.43    0.63    0.62    0.48    0.88    0.22    0.20    0.37    0.37    0.19    0.19    0.09
  5.    0.11    0.35    0.30    0.77    0.91    0.58    0.56    0.69    0.34    0.32    0.37    0.42    0.19    0.29    0.12
 10.    0.16    0.43    0.42    0.46    0.60    0.65    0.50    0.71    0.41    0.32    0.43    0.50    0.30    0.34    0.19
 15.    0.21    0.36    0.49    0.36    0.37    0.42    0.35    0.67    0.49    0.37    0.51    0.61    0.40    0.40    0.28
 20.    0.20    0.26    0.34    0.35    0.29    0.24    0.42    0.39    0.38    0.37    0.43    0.53    0.39    0.42    0.31
 30.    0.20    0.28    0.23    0.23    0.26    0.25    0.15    0.14    0.30    0.19    0.15    0.18    0.40    0.28    0.33
 40.    0.30    0.22    0.21    0.20    0.21    0.21    0.20    0.33    0.16    0.21    0.24    0.20    0.25    0.29    0.38
 50.    0.38    0.23    0.26    0.16    0.20    0.18    0.24    0.62    0.14    0.37    0.27    0.21    0.32    0.22    0.23
 60.    0.36    0.23    0.22    0.16    0.20    0.23    0.22    0.20    0.17    0.43    0.27    0.30    0.29    0.25    0.16
 75.    0.19    0.20    0.17    0.15    0.17    0.20    0.19    0.23    0.16    0.21    0.15    0.18    0.18    0.10    0.05
 90.    0.06    0.08    0.07    0.08    0.08    0.13    0.10    0.19    0.10    0.11    0.09   -0.01    0.06    0.02    0.06
105.    0.09    0.10    0.08    0.05    0.02    0.05    0.06    0.10    0.03    0.05    0.02    0.01    0.02    0.03   -0.00

TOTAL MG PER SQUARE METER
       22.00   23.32   24.97   22.77   26.03   25.73   23.76   33.47   21.52   26.17   24.48   23.96   24.53   21.49   18.13
AVERAGE MG PER CUBIC METER
        0.21    0.22    0.24    0.22    0.25    0.25    0.23    0.32    0.20    0.25    0.23    0.23    0.23    0.20    0.17
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER,DAY
      165.02  185.14  222.67  177.70  201.92  186.60  243.86  269.33  182.73  183.62  173.42  167.59  169.16  124.39  147.46
AVERAGE MG C/CUBIC METER,DAY
        1.57    1.76    2.12    1.69    1.92    1.78    2.32    2.57    1.74    1.75    1.65    1.60    1.61    1.18    1.40
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        0.55    0.57    0.73    0.60    0.71    0.79    0.83    1.17    0.68    0.69    0.69    0.71    0.79    1.00    0.97
  LAKE TAHOE 1971  *****PRIMARY PRODUCTIVITY*****
  ************************************************
  MILLIGRAM OF CARBON PER CUBIC METER PER HOUR

DEPTH  11/24   12/ 6   12/16
 (M)
  0.    0.08    0.04    0.06
  2.    0.11    0.10    0.08
  5.    0.17    0.21    0.14
 10.    0.30    0.30    0.29
 15.    0.39    0.44    0.33
 20.    0.44    0.49    0.50
 30.    0.48    0.47    0.55
 40.    0.30    0.32    0.46
 50.    0.20    0.20    0.30
 60.    0.14    0.11    0.16
 75.    0.08    0.05    0.07
 90.    0.04    0.03    0.02
105.    0.02   -0.03    0.01

TOTAL MG PER SQUARE METER
       21.34   20.84   24.19
AVERAGE MG PER CUBIC METER
        0.20    0.20    0.23
TOTAL PRIMARY PRODUCTIVITY MG C/SQUARE METER.DAY
      124.51  125.05  145.24
AVERAGE MG C/CUBIC METER.DAY
        1.19    1.19    1.38
TOTAL EFFICIENCY (PER CALORIE OF LIGHT)  (X .0001)
        1.42    1.39    1.16
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APPENDIX C

LAKE TAHOE PHYTOPLANKTON SPECIES NUMBERS

Average number of individuals per milliliter for the entire 105-m water column at the index station of Lake Tahoe for each phytoplankton species, 1967-1971.

LAKE TAHOE 1967*****PHYTOPLANKTON*****

AVERAGE NUMBER OF INDIVIDUALS PER ML

	DATE / SPEC.	9/8	18/8	25/8	2/9	7/9	10/9	21/9	28/9	5/10	11/10	18/10	26/10	1/11	9/11	15/11	1/12	8/12
1	CYCLOTELLA ANTIQUA		0.01						0.01		0.01				0.02		0.03	
2	CYCLOTELLA BODANICA	3.78	1.81	2.67	6.56	2.26	5.06	7.99	7.67	9.05	4.25	5.64	6.42	6.15	6.34	6.99	8.34	4.76
3	CYCLOTELLA OCELLATA	0.07	0.06		0.07	0.06	0.01	0.08	0.03		0.03		0.61	0.15	0.31	0.97	0.70	0.28
4	CYCLOTELLA STELLIGERA																0.03	
5	MELOSIRA CRENULATA	3.70	0.97	0.38	0.21	0.23	0.31	0.05	0.15	2.61	0.57	0.59	0.76	0.72	0.32	0.95	0.97	3.28
6	MELOSIRA GRANULATA																	
7	MELOSIRA VARIANS			0.12														
8	MELOSIRA UNDULATA																	
9	STEPHANODISCUS ASTRAEA	0.11	0.53	0.76	3.27	1.93	1.66	1.39	0.83	0.99	0.91	1.15	1.42	0.86	0.97	1.37	0.91	0.43
10	ACHNANTHES CLEVEI	0.04	0.09	0.02	0.03						0.03	0.01	0.11	0.01	0.06	0.07	0.15	0.06
11	ACHNANTHES EXIGUA		0.03	0.12	0.21	0.13	0.02	0.00	0.10		0.02		0.05	0.01	0.01		0.03	
12	ACHNANTHES FLEXELLA	0.01	0.03	0.18		0.05			0.01	0.11		0.04		0.05	0.01		0.03	
13	ACHNANTHES LANCEOLATA	0.03	0.23	0.10	0.17	0.24	0.16	0.12	0.14	0.17	0.15	0.03	0.26	0.04	0.25	0.01	0.08	0.15
14	ACHNANTHES LINEARIS	0.25	0.52	0.51	0.76	0.19	0.23	0.21	0.47	0.16	0.17	0.19	0.41	0.15	0.10	0.30	0.39	0.04
15	ACHNANTHES NOLLII																	
16	ACHNANTHES PERAGALLI																	
17	AMPHIPRORA PALUDOSA						0.02						0.02					
18	AMPHIPLEURA PELLUCIDA	0.01	0.05		0.03			0.03		0.02			0.01		0.02	0.01	0.01	
19	AMPHORA OVALIS	0.04	0.22	0.18	0.28	0.16	0.03	0.07	0.10	0.04		0.11	0.18	0.01	0.07	0.34	0.31	0.10
20	ASTERIONELLA FORMOSA										0.03		0.04	0.06	0.04	0.07	0.02	
21	COCCONEIS DISCULUS																	
22	COCCONEIS PLACENTULA	0.15	0.41	0.35	0.42	0.26	0.23	0.40	0.14	0.26	0.26	0.17	0.85	0.29	0.23	0.64	0.55	0.26
23	COCCONEIS RUGOSA	0.02	0.05												0.03	0.04	0.01	0.01
24	CYMBELLA CUSPIDATA		0.10					0.03		0.01	0.02				0.04	0.03		
25	CYMBELLA GRACILIS																	
26	CYMBELLA LANCEOLATA	0.05			0.04		0.04	0.05	0.02	0.12		0.06	0.19	0.03	0.02	0.14	0.03	
27	CYMBELLA VENTRICOSA	0.04	0.38	0.18	0.37	0.35	0.11	0.10	0.31	0.01	0.16	0.09	0.19	0.06	0.07	0.17	0.05	0.13
28	CYMBELLA SINUATA		0.01		0.09		0.03	0.01		0.02			0.07			0.01		0.04
29	CYMBELLA PROSTRATA																	
30	CYMATOPLEURA SOLEA						0.03											
31	DIATOMA ANCEPS																	
32	DIATOMA HIEMALE		0.05	0.09	0.07	0.06	0.02	0.00	0.03			0.06	0.04		0.05			
33	DIATOMA VULGARE																	
34	DIPLONEIS ELLIPTICA	0.02	0.05	0.05	0.01	0.06	0.08		0.04	0.16	0.06	0.04	0.20	0.09	0.14	0.11	0.10	0.03
35	DIPLONEIS OCULATA		0.03				0.02						0.08			0.07	0.03	
36	DIPLONEIS FINNICA																	
37	EUNOTIA NAEGELII						0.02		0.01	0.01								
38	EUNOTIA TENELLA				0.02													
39	EUNOTIA TRIODON																	
40	EUNOTIA PERPUSILLA																	
41	EUNOTIA PECTINALIS VENT.																	
42	EUNOTIA PECTINALIS																	
43	EPITHEMIA SOREX	0.45	0.65	1.12	1.13	0.73	0.52	0.33	0.63	1.22	0.33	0.16	0.48	0.62	0.42	0.47	0.84	0.12
44	EPITHEMIA TURGIDA																	
45	EPITHEMIA ZEBRA	0.13	0.04				0.06	0.14	0.17	0.27	0.07	0.16	0.19	0.11	0.13	0.27	0.43	0.02
46	EPITHEMIA ARGUS																	
47	FRAGILARIA CROTONENSIS	26.20	12.43	42.79	72.54	31.29	25.40	24.38	12.60	39.66	16.46	11.49	12.77	14.90	11.65		15.52	18.96
48	FRAGILARIA INTERMEDIA																	
49	FRAGILARIA PINNATA	11.17	17.84	11.64	24.38	27.48	12.41	15.75	18.53	12.08	10.17	5.63	22.36	12.55	11.35	13.12	28.53	5.38
50	FRAGILARIA VAUCHERIAE												0.04					
51	FRAGILARIA CONSTRUENS																	
52	FRAGILARIA LEPTOSTAURON																	
53	FRAGILARIA CAPUCINA																	
54	FRUSTULIA RHOMBOIDES						0.01									0.01		
55	GOMPHONEMA ACUMINATUM		0.16				0.05				0.03						0.04	0.08
56	GOMPHONEMA PARVULUM	0.04	0.31	0.34	0.40	0.24	0.12	0.10	0.12	0.21	0.04		0.06	0.11	0.22	0.21	0.14	0.03
57	GOMPHONEMA CAPITATUM																	
58	GOMPHONEMA VENTRICOSUM																	
59	HANTZSCHIA AMPHIOXYS																	
60	GYROSIGMA ATTENUATUM										0.01		0.08	0.02	0.03	0.04		
61	HANNEA ARCUS	0.07		0.01	0.06		0.03		0.07	0.01	0.07		0.02			0.04		
62	MASTOGLOIA SMITHII	0.03	0.14	0.12	0.21	0.31	0.02	0.17	0.11	0.19	0.08		0.12	0.13	0.03	0.13	0.05	
63	MERIDION CIRCULARE				0.03									0.04				0.01
64	NAVICULA AURORA	0.05	0.09		0.10	0.14	0.03	0.04	0.05	0.11	0.03		0.05	0.04	0.04	0.04	0.01	0.02

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                         LAKE TAHOE 1967*****PHYTOPLANKTON*****
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                         AVERAGE NUMBER OF INDIVIDUALS PER ML

                               DATE=   9/ 8   16/ 8   25/ 8    2/ 9    7/ 9   14/ 9   21/ 9   28/ 9    5/10   11/10   18/10   26/10    1/11    5/11   15/11    1/12    8/12
                            SPEC.
 65  NAVICULA BACILLUM                 0.03    0.07    0.09    0.15    0.12    0.02    0.14    0.05    0.14    0.09    0.08    0.16    0.06    0.05    0.10    0.09    0.08
 66  NAVICULA COCCONEIFORMIS       ********************************    0.07************************************************    0.08    0.01********************************
 67  NAVICULA EXIGUA                   0.12    0.09    0.08    0.14    0.08****************    0.05********    0.02********    0.03    0.04    0.10    0.03    0.07********
 68  NAVICULA FESTIVA              ****************************************************************************************************************************************
 69  NAVICULA MUTICA               ****************    0.01************************************************************************************************************************
 70  NAVICULA PSEUDOSCUTIFORM.         0.02    0.05    0.19********    0.01    0.02********************************    0.01****************    0.02********    0.07********
 71  NAVICULA PUPULA                   0.14    0.20********    0.35    0.07    0.14    0.09    0.15    0.18    0.10    0.04    0.37    0.09    0.14    0.37    0.34    0.60
 72  NAVICULA RADIOSA                  0.21    0.56    3.43    0.59    1.00    0.58    0.42    0.46    0.74    0.46    0.14    0.76    0.39    0.46    0.77    0.88    0.19
 73  NAVICULA SCUTELLOIDES         ****************************************************************************************    0.01****************************************
 74  NAVICULA CAPITATA             ****************************************************************************************************************************************
 75  NAVICULA CUSPIDATA            ****************************************************************************************************************************************
 76  NAVICULA COSTULATA            ****************************************************************************************************************************************
 77  NEIDIUM HITCHCOCKII           ****************************************************************************************************************************************
 78  NEIDIUM AFFINE                ****************************************************************************************************************************************
 79  NITZSCHIA FILIFORMIS              0.01    0.03    0.08    0.13    0.24    0.04    0.03    0.02    0.08    0.08    0.02    0.04********    0.02    0.10    0.09    0.03
 80  NITZSCHIA AMPHIBIA                0.02    0.15****************    0.08********    0.03****************    0.02********    0.01********    0.03********    0.03********
 81  NITZSCHIA SINUATA             ****************************************************************************************************************************************
 82  NITZSCHIA PALEA               ****************************************************************************************************************************************
 83  OPEPHORA MARTYI               ********    0.11****************    0.04************************    0.08    0.03********    0.44********    0.08    0.10    0.05    0.01
 84  OPEPHORA AMERICANA            ****************************************************************************************************************************************
 85  PINNULARIA BICEPS                 0.03****************    0.03    0.06****************************************    0.02    0.01    0.04    0.01********    0.03********
 86  PINNULARIA AESTUARII          ****************************************************************************************************************************************
 87  PINNULARIA SUBCAPITATA        ****************************************************************************************************************************************
 88  PINNULARIA ABAUJENSIS         ****************************************************************************************************************************************
 89  PINNULARIA RUPESTRIS          ****************************************************************************************************************************************
 90  RHOICOSPHENIA CURVATA         ****************************************************************    0.01************************************************    0.03********
 91  RHOPALODIA GIBBA                  0.07    0.10    0.11    0.20    0.25    0.12    0.04    0.09    0.15    0.05    0.17    0.15    0.05    0.09    0.01    0.07    0.15
 92  STAURONEIS PHOENICENTERON         0.02************************    0.04************************************************    0.02    0.01********    0.02    0.01    0.01
 93  STAURONEIS SMITHII            ********************************************************************************************************************************    0.04********
 94  STAURONEIS ANCEPS             ****************************************************************************************************************************************
 95  SURIRELLA OVATA                   0.02    0.03    0.01********    0.06********    0.03********    0.04    0.02********    0.01    0.02    0.04********    0.05    0.01
 96  SYNEDRA AMPHICEPHALA              0.12    0.21    0.20    0.20    0.15    0.12    0.08    0.13    0.13    0.07    0.04    0.04    0.04    0.07********    0.06    0.01
 97  SYNEDRA KAZANENSIS            ****************************************************************************************************************************************
 98  SYNEDRA RADIANS               ********    0.02    0.02    0.02****************************************************************************************    0.01    0.08********
 99  SYNEDRA RUMPENS               ************************    0.02    0.02****************    0.12****************    0.01****************    0.01********    0.06********
100  SYNEDRA SOCIA                 ****************    0.01************************************************************************************************************************
101  SYNEDRA ULNA                      0.03    0.05    0.21    0.18    0.12    0.04********    0.07    0.06    0.01    0.01    0.09    0.01    0.05    0.01    0.12    0.11
102  SYNEDRA INCISA                ****************************************************************************************************************************************
103  TABELLARIA FENESTRATA         ****************************************************************************************************************************************
104  TABELLARIA FLOCCULOSA         ****************************************************************************************************************************************
105  TETRACYCLUS EMARGINATUS       ********************************************************************************************************************************    0.06********
106  TETRACYCLUS LACUSTRIS         ****************************************************************************************************************************************
107  DIATOMELLA BALFOURIANA        ****************************************************************************************************************************************
108  ACTINOCYCLUS EHRENBERGII      ****************************************************************************************************************************************
109  CALONEIS FENZLII              ****************************************************************************************************************************************
110  CALONEIS SPECIOSA             ****************************************************************************************************************************************
111  BIDDULPHIA AURITA             ****************************************************************************************************************************************
112  GOMPHONEIS HERCULEANA         ****************************************************************************************************************************************
113  ELAKATOTHRIX GELATINOSA           0.58    0.36****************    0.68****************    0.31    3.39    1.95    1.24    0.73    0.42    0.49    1.22    0.85    0.08
114  SCENEDESMUS QUADRICAUDA       ************************************************************************************************************************    0.03    0.01
115  SPHAEROCYSTIS SCHROETERI          2.64    4.72    7.64   15.53   11.27    8.07   39.77   57.91   38.06   15.95   43.65   60.35   65.22   94.84   49.03   73.36    9.75
116  STAURASTRUM PARADOXUM         ****************    0.03****************    0.02****************    0.19****************    0.03****************    0.03********    0.02
117  BOTRYOCOCCUS BRAUNII          ****************************************************************************************************************************************
118  OOCYSTIS NAEGELII             ****************************************************************************************************************************************
119  PEDIASTRUM KAWRAISKYI         ****************************************************************************************************************************************
120  ULOTHRIX AEQUALIS             ****************************************************************************************************************************************
121  ANABAENA SP.                  ********************************************************************************************************************************    0.06********
122  MERISMOPEDIA ELEGANS          ****************************************************************************************************************************************
123  POLYCYSTIS AERUGINOSA         ****************************************************************************************************************************************
124  DINOBRYON SERTULARIA          ****************************************************************************************************************************************
125  KEPHYRION OVUM                ****************************************************************************************************************************************
126  MALLOMONAS                    ****************************************************************************************************************************************
127  PERIDINIUM SP.                    0.51    0.52    0.07    0.76    0.47    0.63    0.09    0.02    0.21    0.79    0.04    2.63    1.47    2.73    5.12    2.66    0.01
128  CERATIUM HIRUNDINELLA         ********************************************************    0.01********    0.91****************    0.01********    0.09****************
129  CRYPTOMONAS REFLEXA           ****************************************************************************************************************************************
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LAKE TAHOE 1969******PHYTOPLANKTON******
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AVERAGE NUMBER OF INDIVIDUALS PER ML

                            DATE*    2/ 1   16/ 1   29/ 1    8/ 2   18/ 2   20/ 2   28/ 2    6/ 3   13/ 3   20/ 3   26/ 3    2/ 4   11/ 4   18/ 4   25/ 4    1/ 5    9/ 5
                        SPEC.
  1  CYCLOTELLA ANTIGUA            ********    0.02************************************************************************************************************************
  2  CYCLOTELLA BODANICA               7.04    5.22    6.94    4.93    4.76    4.42    5.16    5.08    5.88    6.62    3.74    5.15    4.24    3.27    3.07    3.21    3.46
  3  CYCLOTELLA OCELLATA               0.47    0.26    0.64    2.53    2.42    2.04    2.17    2.73    4.19    2.58    1.76    1.71    1.40    2.99    1.19    1.25    1.26
  4  CYCLOTELLA STELLIGERA         ************************************************    0.07********************************************************************************
  5  MELOSIRA CRENULATA                2.24    2.56    7.15    7.22   11.32    9.29   13.72   15.52   13.28   22.79   26.19   21.36   13.24   20.92    6.53   18.80    8.92
  6  MELOSIRA GRANULATA            ********************************************************************************************************************************    0.02
  7  MELOSIRA VARIANS              ********************************************************************************************************************************    0.05
  8  MELOSIRA UNDULATA             ****************************************************************************************************************************************
  9  STEPHANODISCUS ASTREA             1.22    0.92    2.37    2.89    2.09    3.88    4.69    5.61    3.88    8.10    7.04    5.51    5.08    7.12    5.20    5.89    6.27
 10  ACHNANTHES CLEVEI                 0.09    0.11********    0.19    0.02    0.21    0.06    0.04    0.17    0.16********    0.02    0.31****************    0.05    0.05
 11  ACHNANTHES EXIGUA                 0.01********    0.06    0.04********    0.06****************************************************************************************
 12  ACHNANTHES FLEXELLA           ********************************************************    0.01********    0.29********    0.04****************************************
 13  ACHNANTHES LANCEOLATA             0.09    0.02    0.15    0.28    0.14    0.04    0.33    0.10    0.19    0.44    0.17********    0.09    0.03    0.06    0.28    0.07
 14  ACHNANTHES LINEARIS               0.10    0.02    0.47    0.61    0.86    0.60    0.50    0.87    1.47    1.01    0.83    0.46    1.36    2.44    1.83    2.07    1.30
 15  ACHNANTHES MOLLII             ********************************************************************************    0.11********************************    0.05    0.14
 16  ACHNANTHES PERAGALLI          ************************************************    0.06    0.02    0.04****************    0.02****************    0.07****************
 17  AMPHIPRORA PALUDOSA           ********************************************************    0.02****************************************************************************
 18  AMPHIPLEURA PELLUCIDA         ****************    0.01****************    0.02************************************************    0.01********************************
 19  AMPHORA OVALIS                    0.04    0.10    0.18    0.28    0.09    0.15    0.16    0.39    0.56    0.53    0.19    0.19    0.34    0.47    0.38    0.26    0.25
 20  ASTERIONELLA FORMOSA              0.25    0.01    0.36    0.21    0.43    0.90    0.22    0.08********    0.06********    0.08****************    0.02    0.11********
 21  COCCONEIS DISCULUS            ********************************************************************************    0.40    0.09    0.08    0.08    0.18    0.01    0.02
 22  COCCONEIS PLACENTULA              0.25    0.14    0.45    0.05    0.19    0.35    0.31    1.68    0.07    0.49    0.32    0.06    0.30    0.49    0.11    0.28    0.34
 23  COCCONEIS RUGOSA                  0.04    0.10    0.01********    0.01    0.01********************************************************    0.08************************
 24  CYMBELLA CUSPIDATA            ********************************************************************************************************************************    0.04
 25  CYMBELLA GRACILIS             ************************************************************************************************    0.01************************    0.07
 26  CYMBELLA LANCEOLATA           ****************    0.03****************************************    0.08****************************************************************
 27  CYMBELLA VENTRICOSA               0.12    0.05    0.04    0.09    0.06    0.03    0.10    0.13    0.16    0.14    0.19    0.01    0.06    0.13    0.13    0.10    0.33
 28  CYMBELLA SINUATA                  0.01****************************************    0.03********    0.08********    0.04************************    0.04********    0.05    0.07
 29  CYMBELLA PROSTRATA            ****************************************************************************************************************************************
 30  CYMATOPLEURA SOLEA            ****************************************************************************************************************************************
 31  DIATOMA ANCEPS                ****************************************************************************************************************************************
 32  DIATOMA HIEMALE                   0.03********************************    0.02********    0.08    0.08****************    0.12    0.08    0.06    0.06    0.06    0.11
 33  DIATOMA VULGARE               ****************************************************************************************************************************************
 34  DIPLONEIS ELLIPTICA               0.04    0.03    0.02    0.01    0.14    0.10********    0.03    0.10    0.17    0.02    0.02****************    0.06    0.02********
 35  DIPLONEIS OCULATA                 0.03    0.01    0.05    0.10    0.08    0.20    0.04********    0.15********    0.05    0.03    0.06    0.35    0.07    0.03    0.05
 36  DIPLONEIS FINNICA             ****************************************************************************************************************************************
 37  EUNOTIA NAEGELII              ********    0.01************************    0.08********************************    0.07    0.02****************************************
 38  EUNOTIA TENELLA               ************************************************    0.06****************    0.01****************************************    0.06********
 39  EUNOTIA TRIODON               ****************************************    0.02****************************************************************************************
 40  EUNOTIA PERPUSILLA            ****************************************************************************************************************************************
 41  EUNOTIA PECTINALIS VENT.      ****************************************************************************************************************************************
 42  EUNOTIA PECTINALIS            ****************************************************************************************************************************************
 43  EPITHEMIA SOREX                   0.34    0.14    0.09    0.01    0.14    0.42    0.15    0.33    0.14    0.53    0.07    0.04    0.33    0.19    0.13    0.14    0.26
 44  EPITHEMIA TURGIDA             ************************    0.01****************************************    0.06****************    0.08********    0.02****************
 45  EPITHEMIA ZEBRA                   0.14    0.04    0.07    0.15    0.05    0.13    0.15    0.05    0.10    0.10    0.15    0.02    0.01    0.10    0.10    0.07********
 46  EPITHEMIA ARGUS               ****************************************************************************************************************************************
 47  FRAGILARIA CROTONENSIS           31.15   44.68   64.95   81.12  101.20  111.39  117.15  182.49  167.71  155.70  134.52  162.17  133.25  185.47  112.19  124.13  137.49
 48  FRAGILARIA INTERMEDIA         ****************************************************************************************************************************************
 49  FRAGILARIA PINNATA                8.31    3.86    5.07    8.21    6.60    5.65    3.65   12.98    7.24    4.65    6.07    3.37    5.90   12.50    6.28    4.10    4.29
 50  FRAGILARIA VAUCHERIAE         ****************************************************************    0.04************************    0.08    0.06    0.02    0.26********
 51  FRAGILARIA CONSTRUENS         ****************************************************************************************************************************************
 52  FRAGILARIA LEPTOSTAURON       ****************************************************************************************************************************************
 53  FRAGILARIA CAPUCINA           ****************************************************************************************************************************************
 54  FRUSTULIA RHOMBOIDES          ************************************************************************    0.01****************************************************************
 55  GOMPHONEMA ACUMINATUM             0.05    0.01********    0.01    0.02    0.06********    0.02********************************    0.08************************    0.03********
 56  GOMPHONEMA PARVULUM               0.06    0.08    0.19    0.15    0.07    0.17    0.37    0.12    0.25    0.41    0.32    0.11    0.09    0.46    0.38    0.61    0.10
 57  GOMPHONEMA CAPITATUM          ****************************************************************************************************************************************
 58  GOMPHONEMA VENTRICOSUM        ****************************************************************************************************************************************
 59  HANTZSCHIA AMPHIOXYS          ********************************************************************************************************************************    0.07
 60  GYROSIGMA ATTENUATUM              0.01********************************************************************************************************************************
 61  HANNEA ARCUS                  ****************    0.00****************************    0.02************************************************    0.01****************    0.07
 62  MASTOGLOIA SMITHII                0.06****************************************    0.08****************************************    0.02    0.06********    0.01********
 63  MERIDION CIRCULARE            ****************************************    0.01************************************************    0.02********************************
 64  NAVICULA AURORA               ********    0.06    0.05    0.02    0.08    0.07    0.02****************    0.01    0.07    0.02    0.01    0.06********    0.03    0.07
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LAKE TAHOE 1968******PHYTOPLANKTON******

AVERAGE NUMBER OF INDIVIDUALS PER ML

	SPEC. / DATE=	2/ 1	16/ 1	29/ 1	9/ 2	18/ 2	20/ 2	28/ 2	6/ 3	13/ 3	20/ 3	26/ 3	2/ 4	11/ 4	18/ 4	25/ 4	1/ 5	9/ 5
65	NAVICULA BACILLUM			0.02	0.07				0.08	0.07	0.06			0.01	0.10	0.14	0.02	
66	NAVICULA COCCONEIFORMIS			0.10											0.08		0.02	
67	NAVICULA EXIGUA	0.03	0.03	0.02	0.02	0.06		0.01	0.02	0.08	0.01			0.02	0.01	0.04	0.14	0.08
68	NAVICULA FESTIVA					0.01	0.28	0.20	0.65	0.15	0.41	0.22	0.22					
69	NAVICULA MUTICA																	
70	NAVICULA PSEUDOSCUTIFORM.	0.04		0.03	0.02	0.10	0.10	0.12	0.06	0.03	0.06	0.19	0.08	0.08	0.11	0.08	0.03	0.11
71	NAVICULA PUPULA	0.12	0.19	0.09	0.12	0.06	0.06	0.17	0.26		0.06	0.13		0.14	0.20	0.09	0.07	0.10
72	NAVICULA RADIOSA	0.64	0.25	0.20	0.29	0.25	0.39	0.37	0.47	0.17	0.54	0.22	0.08	0.49	0.60	0.81	0.57	0.17
73	NAVICULA SCUTELLOIDES																	
74	NAVICULA CAPITATA																	
75	NAVICULA CUSPIDATA																	
76	NAVICULA COSTULATA																	
77	NEIDIUM HITCHCOCKII																	
78	NEIDIUM AFFINE																	
79	NITZSCHIA FILIFORMIS	0.08	0.02	0.02	0.32	0.62	0.46	0.72	1.22	1.68	1.34	1.26	1.76	1.41	2.04	1.58	1.55	0.78
80	NITZSCHIA AMPHIBIA	0.02	0.01	0.03	0.15	0.40	0.37	0.67	0.31	0.38	0.22	0.29	1.66	0.28	1.33	1.78	1.06	0.71
81	NITZSCHIA SINUATA																	
82	NITZSCHIA PALEA																	
83	OPEPHORA MARTYI						0.17							0.02				
84	OPEPHORA AMERICANA																	
85	PINNULARIA BICEPS	0.02		0.02	0.01	0.11	0.06			0.08						0.01	0.03	0.17
86	PINNULARIA AESTUARII											0.04						
87	PINNULARIA SUBCAPITATA								0.11									
88	PINNULARIA ABAUJENSIS																	
89	PINNULARIA RUPESTRIS																	
90	RHOICOSPHENIA CURVATA	0.01			0.08				0.03			0.07			0.01			
91	RHOPALODIA GIBBA	0.12	0.04	0.02	0.14	0.02	0.08		[illegible]	0.02					0.21	0.02	0.05	
92	STAURONEIS PHOENICENTERON	0.01				0.08			0.04					0.01			0.01	
93	STAURONEIS SMITHII	0.01			0.01		0.01				0.04							
94	STAURONEIS ANCEPS																	
95	SURIRELLA OVATA	0.01						0.02	0.01								0.14	
96	SYNEDRA AMPHICEPHALA	0.14	0.03	0.01	0.28	0.03	0.24	0.08	0.08	0.22	0.04	0.11	0.01	0.06	0.26	0.13		0.23
97	SYNEDRA MAZAMAENSIS						0.01		0.32		0.17			0.08	0.19		0.27	0.02
98	SYNEDRA RADIANS							0.01	0.33		0.06						0.03	
99	SYNEDRA RUMPENS					0.02		0.01	0.03					0.08		0.06	0.10	
100	SYNEDRA SOCIA																	
101	SYNEDRA ULNA	0.08	0.02	0.06		0.08	0.01		0.01		0.08		0.07	0.01	0.04	0.19	0.03	
102	SYNEDRA INCISA									0.01								
103	TABELLARIA FENESTRATA							0.01	0.08						0.08			0.07
104	TABELLARIA FLOCCULOSA	0.01				0.02			0.02									
105	TETRACYCLUS EMARGINATUS																	
106	TETRACYCLUS LACUSTRIS																	
107	DIATOMELLA BALFOURIANA																	
108	ACTINOCYCLUS EHRENBERGII																	
109	CALONEIS FENZLII																	
110	CALONEIS SPECIOSA																	
111	BIDDULPHIA AURITA																	
112	GOMPHONEIS HERCULEANA																	
113	ELAKATOTHRIX GELATINOSA	0.44	0.34	0.57	0.32	0.57	0.44	0.28	0.69	0.44	0.56	0.22	0.83		0.15	0.04	0.03	0.02
114	SCENEDESMUS QUADRICAUDA	0.03									0.02							
115	SPHAEROCYSTIS SCHROETERI	39.53	17.43	14.27	3.54	8.03	2.42	8.85	6.64	7.06	1.28	2.79	2.33	1.75	1.17		1.67	0.57
116	STAURASTRUM PARADOXUM		0.01				0.04					0.02		0.04				
117	BOTRYOCOCCUS BRAUNII																	
118	OOCYSTIS NAEGELII																	
119	PEDIASTRUM KAWRAISKYI																	
120	ULOTHRIX AEQUALIS																	
121	ANABAENA SP.																	
122	MERISMOPEDIA ELEGANS																	
123	POLYCYSTIS AERUGINOSA																	
124	DINOBRYON SERTULARIA			2.73	2.41	2.58	1.91	4.49	8.06	3.32	7.79	7.59	7.11	7.53	13.74	16.67	6.49	38.34
125	KEPHYRION OVUM			14.03	28.20	25.47	21.51	15.32	15.45	25.06	9.79	11.13	6.65	3.83	7.22	1.24	3.58	1.02
126	MALLOMONAS																	
127	PERIDINIUM SP.	4.83	4.53	3.97	4.42	3.90	2.70	2.22	0.35	2.76	3.25	1.50	1.92	4.12	3.80	5.88	2.01	3.99
128	CERATIUM HIRUNDINELLA																	
129	CRYPTOMONAS REFLEXA																	

LAKE TAHOE 1968*****PHYTOPLANKTON*****

AVERAGE NUMBER OF INDIVIDUALS PER ML

	DATE= SPEC.	16/5	22/5	29/5	5/6	12/6	19/6	26/6	8/7	11/7	17/7	24/7	31/7	7/8	12/8	21/8	28/8	2/9
1	CYCLOTELLA ANTIQUA							0.04	0.01								0.06	
2	CYCLOTELLA BODANICA	2.49	4.28	3.05	2.65	2.15	0.75	1.74	2.27	1.24	1.30	0.58	1.96	1.65	2.58	1.08	1.88	1.17
3	CYCLOTELLA OCELLATA	1.39	1.45	0.26	3.43	0.09	0.18	0.12	0.34	0.68	0.58	0.42	0.06	0.16		0.10	0.17	0.22
4	CYCLOTELLA STELLIGERA																	
5	MELOSIRA CRENULATA	11.72	35.14	8.16	4.87	3.83	2.00	2.47	2.34	1.91	1.13	0.73	0.91	0.72	0.51	1.19	1.17	1.06
6	MELOSIRA GRANULATA				0.01	0.01								0.08				
7	MELOSIRA VARIANS																	
8	MELOSIRA UNDULATA																	
9	STEPHANODISCUS ASTREA	6.29	8.03	4.81	4.25	5.87	1.27	2.70	3.72	3.17	3.79	4.31	2.63	8.31	6.49	4.72	6.65	6.71
10	ACHNANTHES CLEVEI	0.08	0.04	0.03	0.04	0.08	0.01		0.01	0.01	0.12	0.98	0.08	0.12	0.03	0.02	0.01	
11	ACHNANTHES EXIGUA																	
12	ACHNANTHES FLEXELLA				0.00	0.02					0.06		0.01		0.04	0.01	0.02	0.02
13	ACHNANTHES LANCEOLATA	0.28	0.08	0.12	0.13	0.28	0.06	0.19	0.16	0.02	0.24	0.44	0.22	0.13	0.12	0.21	0.27	0.15
14	ACHNANTHES LINEARIS	2.55	0.41	0.08	0.06	0.12	0.40	0.27	1.61	1.31	2.35	3.69	1.38	1.88	1.19	1.38	1.70	1.22
15	ACHNANTHES NOLLII								0.01		0.02	0.04				0.01	0.01	
16	ACHNANTHES PERAGALLI			0.01	0.01		0.01	0.07				0.08	0.03	0.06	0.06	0.09		
17	AMPHIPRORA PALUDOSA																	
18	AMPHIPLEURA PELLUCIDA						0.01		0.01	0.02		0.04	0.04	0.01	0.03	0.01	0.01	0.04
19	AMPHORA OVALIS	0.49	0.08	0.04		0.05	0.03	0.03	0.15	0.08	0.14	0.45	0.06	0.17	0.06	0.15	0.19	0.10
20	ASTERIONELLA FORMOSA			0.30	0.01	0.08				0.01						0.04	0.08	0.13
21	COCCONEIS DISCULUS	0.09		0.01	0.01	0.07	0.03	0.12	0.01		0.03	0.01	0.03	0.04		0.03	0.02	0.12
22	COCCONEIS PLACENTULA	0.34	0.10	0.03	0.13	0.09	0.07	0.15	0.10	0.09	0.26	0.37	0.19	0.13	0.03	0.25	0.08	0.23
23	COCCONEIS RUGOSA		0.05								0.10	0.06		0.06		0.04	0.03	0.06
24	CYMBELLA CUSPIDATA		0.03					0.00	0.08		0.04				0.01	0.06		0.02
25	CYMBELLA GRACILIS								0.02		0.03	0.04	0.04	0.03	0.10	0.13	0.06	0.01
26	CYMBELLA LANCEOLATA			0.01		0.05	0.01	0.14	0.04	0.09				0.01	0.06	0.04		0.03
27	CYMBELLA VENTRICOSA	0.21	0.11	0.05	0.12	0.10	0.09	0.11	0.32	0.13	0.90	0.40	0.29	0.46	0.05	0.25	0.17	0.41
28	CYMBELLA SINUATA	0.08	0.03	0.04	0.02	0.05	0.04	0.01	0.12	0.17	0.25	0.38	0.20	0.17	0.17	0.17	0.15	0.24
29	CYMBELLA PROSTRATA																	
30	CYMATOPLEURA SOLEA																	
31	DIATOMA ANCEPS			0.01	0.01	0.01		0.08	0.02			0.04		0.02	0.02	0.04	0.04	0.02
32	DIATOMA HIEMALE			0.08		0.02				0.01			0.04	0.01			0.06	
33	DIATOMA VULGARE																	
34	DIPLONEIS ELLIPTICA	0.03	0.02	0.07			0.02	0.13	0.10		0.06	0.06	0.08			0.08	0.02	0.01
35	DIPLONEIS OCULATA	0.11	0.08					0.10			0.02						0.05	
36	DIPLONEIS FINNICA																	
37	EUNOTIA NAEGELII								0.01		0.01							
38	EUNOTIA TENELLA			0.01	0.03					0.01		0.06				0.06	0.01	0.01
39	EUNOTIA TRIODON																	
40	EUNOTIA PERPUSILLA					0.01												
41	EUNOTIA PECTINALIS VENT.																	
42	EUNOTIA PECTINALIS																	
43	EPITHEMIA SOREX	0.27	0.09	0.14	0.08	0.07	0.11	0.37	0.38	0.21	0.36	0.96	0.52	0.69	0.40	0.81	0.72	0.40
44	EPITHEMIA TURGIDA		0.01						0.11		0.12							
45	EPITHEMIA ZEBRA	0.34	0.01	0.04	0.01	0.04	0.01		0.09	0.04	0.09	0.08	0.15	0.26		0.20	0.38	0.21
46	EPITHEMIA ARGUS																	
47	FRAGILARIA CROTONENSIS	128.21	166.02	114.55	69.86	93.16	16.07	5.61	31.39	32.96	25.39	17.88	14.58	10.99	16.90	19.03	14.13	8.92
48	FRAGILARIA INTERMEDIA				0.72	0.60												
49	FRAGILARIA PINNATA	0.17	3.37				3.06	7.20	6.67	5.03	14.62	25.66	16.36	8.82	6.67	15.96	7.83	12.67
50	FRAGILARIA VAUCHERIAE	0.44		0.02														
51	FRAGILARIA CONSTRUENS	0.07																
52	FRAGILARIA LEPTOSTAURON																	
53	FRAGILARIA CAPUCINA																	
54	FRUSTULIA RHOMBOIDES	0.07									0.01			0.04				
55	GOMPHONEMA ACUMINATUM		0.02			0.01	0.03	0.03	0.08	0.06	0.05	0.13			0.10	0.07	0.04	0.06
56	GOMPHONEMA PARVULUM	0.37	0.05	0.13	0.19	0.12	0.07	0.23	0.17	0.26	0.24	0.38	0.19	0.12	0.07	0.15	0.51	0.26
57	GOMPHONEMA CAPITATUM			0.04				0.01	0.02		0.03					0.02		0.08
58	GOMPHONEMA VENTRICOSUM																	
59	HANTZSCHIA AMPHIOXYS						0.01	0.07		0.01	0.03	0.06					0.08	
60	GYROSIGMA ATTENUATUM																	
61	HANNEA ARCUS	0.07		0.04	0.02	0.03			0.01						0.02			
62	MASTOGLOIA SMITHII			0.01	0.02		0.02	0.12	0.02	0.03	0.03	0.24	0.08	0.13	0.09	0.14	0.13	0.13
63	MERIDION CIRCULARE	0.01				0.03	0.01	0.06	0.01	0.04		0.02	0.01		0.04	0.02	0.02	
64	NAVICULA AURORA		0.07	0.01	0.02	0.02	0.01	0.10	0.08	0.02	0.14	0.19	0.04		0.01	0.19	0.01	0.08

LAKE TAHOE 1969******PHYTOPLANKTON*****

AVERAGE NUMBER OF INDIVIDUALS PER ML

	DATE* SPEC.	16/ 5	22/ 5	29/ 5	5/ 6	12/ 6	19/ 6	26/ 6	4/ 7	11/ 7	17/ 7	24/ 7	31/ 7	7/ 8	12/ 8	21/ 8	28/ 8	2/ 9
55	NAVICULA BACILLUM		0.01					0.01	0.01		0.10	0.10	0.10	0.03	0.13	0.05	0.13	0.07
66	NAVICULA COCCONEIFORMIS	0.07	0.02						0.02	0.01	0.03	0.13		0.01		0.04		
67	NAVICULA EXIGUA	0.13	0.07	0.10	0.08	0.05							0.06	0.09	0.03	0.15	0.06	0.01
68	NAVICULA FESTIVA					0.03												
69	NAVICULA MUTICA																	
70	NAVICULA PSEUDOSCUTIFOR.																	
71	NAVICULA PUPULA	0.04					0.01	0.18	0.08	0.13	0.24	0.34	0.10	0.13	0.01	0.35	0.11	0.29
72	NAVICULA RADIOSA	0.14	0.11	0.35	0.01	0.08	0.06	0.03	0.16	0.12	0.19	0.21	0.04	0.18	0.17	0.30	0.17	0.15
73	NAVICULA SCUTTELOIDES	0.50	0.18	0.26	0.17	0.28	0.11	0.13	0.51	0.40	1.27	1.59	0.78	0.92	0.49	0.03	0.92	0.59
74	NAVICULA CAPITATA																	
75	NAVICULA CUSPIDATA						0.01	0.15	0.05	0.06	0.06	0.08						
76	NAVICULA COSTULATA																	
77	NEIDIUM HITCHCOCKII																	
78	NEIDIUM AFFINE							0.09	0.02		0.02			0.03				
79	NITZSCHIA FILLIFORMIS			0.04														
80	NITZSCHIA AMPHIBIA	0.44	2.12	0.03	0.05	0.02		0.11	0.19	0.14	0.13	0.24	0.11	0.40	0.05	0.13	0.41	0.26
81	NITZSCHIA SINUATA	0.05	0.26	0.02	0.04	0.05	0.02	0.04	0.21	0.03	0.24	0.35	0.23	0.28	0.39	0.14	0.31	0.13
82	NITZSCHIA PALEA																	
83	PEPHORA MARTYI																	
84	PEPHORA AMERICANA			0.04	0.11	0.20		0.08	0.10		0.07	0.04	0.04	0.10	0.01	0.21	0.01	0.02
85	PINNULARIA BICEPS																	
86	PINNULARIA AESTUARII			0.01	0.01		0.06	0.09	0.03		0.01	0.10		0.03	0.10	0.24	0.08	0.08
87	PINNULARIA SUBCAPITATA																	
88	PINNULARIA ABAUJENSIS			0.01								0.13						
89	PINNULARIA RUPESTRIS																	
90	RHOICOSPHENIA CURVATA																	
91	RHOPALODIA GIBBA			0.01									0.02					
92	STAURONEIS PHOENICENTERON	0.01		0.04	0.05	0.01	0.07	0.00	0.01	0.01	0.03	0.21	0.01	0.16		0.02	0.07	0.12
93	STAURONEIS SMITHII					0.01				0.01		0.04		0.01	0.04			
94	STAURONEIS ANCEPS				0.01													
95	SURIRELLA OVATA																	
96	SYNEDRA AMPHICEPHALA	0.07		0.04			0.01		0.01		0.04	0.04	0.06	0.01			0.10	
97	SYNEDRA MAZAMENSIS	0.42	0.12				0.04	0.21	0.08	0.24	0.21	0.34	0.15	0.24	0.19	0.08	0.30	0.12
98	SYNEDRA RADIANS	0.35		0.01		0.07		0.00			0.03	0.04						
99	SYNEDRA RUMPENS	0.07											0.09		0.03		0.06	
100	SYNEDRA SOCIA	0.84	0.02		0.02	0.01	0.01	0.23	0.10	0.03	0.06				0.01		0.01	0.03
101	SYNEDRA ULNA								0.10			0.11	0.01	0.01	0.12	0.06	0.03	0.08
102	SYNEDRA INCISA	0.05		0.04	0.02	0.01	0.04	0.19	0.01	0.11	0.10	0.02	0.10	0.00	0.04	0.06	0.03	0.04
103	TABELLARIA FENESTRATA			0.07	0.03	0.18		0.14		0.01								
104	TABELLARIA FLOCCULOSA	0.07						0.06	0.01		0.08							
105	TETRACYCLUS EMARGINATUS			0.01														
106	TETRACYCLUS LACUSTRIS											0.04						0.01
107	DIATOMELLA BALFOURIANA																	
108	ACTINOCYCLUS EHRENBERGII								0.01								0.06	
109	CALONEIS FENZLII																	
110	CALONEIS SPECIOSA																	
111	BIDDULPHIA AURITA																	
112	GOMPHONEIS HERCULEANA																	
113	ELAKATOTHRIX GELATINOSA																	
114	SCENEDESMUS QUADRICAUDA	0.28	0.31			0.10	0.13	0.09	0.13		0.44	0.50	0.76	0.35	1.62	1.38	1.97	0.97
115	SPHAEROCYSTIS SCHROETERI											0.04	0.01			0.04		
116	STAURASTRUM PARADOXUM	0.22		0.04	0.02	0.03	1.61	1.78		1.78	0.33	0.22			0.17	1.00		
117	BOTRYOCOCCUS BRAUNII	0.02	0.02			0.01	0.02	0.04	0.06		0.05							0.06
118	OOCYSTIS NAEGELII																	
119	PEDIASTRUM KAWRAISKYI																	
120	ULOTHRIX AEQUALIS																	
121	ANABAENA SP.																	
122	MERISMOPEDIA ELEGANS																	
123	POLYCYSTIS AERUGINOSA																	
124	DINOBRYON SERTULARIA																	
125	KEPHYRION OVUM	18.99	6.74	0.06	0.70	0.65	0.13		0.28		0.33	0.10	0.10		0.83	0.85	0.60	1.07
126	MALLOMONAS	1.33	5.05									0.06					1.02	0.69
127	PERIDINIUM SP.																	
128	CERATIUM HIRUNDINELLA	5.69	2.25				0.22	0.31	0.63	0.78	4.38	1.76	5.32	3.63	4.09	9.44	11.99	9.08
129	CRYPTOMONAS REFLEXA																	

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LAKE TAHOE 1968-1969*****PHYTOPLANKTON*****
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AVERAGE NUMBER OF INDIVIDUALS PER ML

                                DATE*  11/ 9   17/ 9   26/ 9   15/10   19/10   27/10    2/11    1/12    7/12   22/12   16/ 1    1/ 2   15/ 2    2/ 3   15/ 3   30/ 3   13/ 4
                              SPEC.
 1 CYCLOTELLA ANTIGUA                  0.04************************    0.08****************    0.03    0.02********    0.01    0.01********************************    0.01
 2 CYCLOTELLA RUDANICA                 1.90    0.74    2.98    1.99    1.81    3.10    2.97    1.99    2.95    2.16    3.50    2.95    2.41    2.75    2.07    1.93    2.06
 3 CYCLOTELLA OCELLATA                 0.04    0.49    1.06    1.54    1.77    1.59    1.79    1.06    1.25    0.51    1.35    1.90    1.64    1.09    0.69    1.44    1.09
 4 CYCLOTELLA STELLIGERA           ********************************************************    0.01    0.14    0.32    0.01********************************************
 5 MELOSIRA CRENULATA                  0.44    0.23    0.39    0.92    1.27    0.59    1.07    0.67    0.51    0.56    2.09    6.32    6.33    9.16    9.89   10.60   11.16
 6 MELOSIRA GRANULATA              ************************************************    0.01    0.03    0.01    0.08    0.02********    0.03****************************    0.11
 7 MELOSIRA VARIANS                ****************************************************************    0.01********    0.01    0.01************************    0.03********
 8 MELOSIRA UNDULATA               ****************************************************************************************************************************************
 9 STEPHANODISCUS ASTREA               5.64    1.66    6.08    5.40    5.03    4.49    2.71    1.72    2.66    2.33    2.55    1.65    3.31    3.98    4.43    4.40    5.07
10 ACHNANTHES CLEVEI                   0.01    0.11    0.04    0.13    0.17    0.06    0.08    0.16    0.08    0.07    0.04    0.02    0.05    0.12    0.09    0.05    0.02
11 ACHNANTHES EXIGUA               ****************    0.01    0.06    0.01    0.01    0.03    0.03********    0.01************************    0.00    0.02    0.05********
12 ACHNANTHES FLEXELLA             ********************************    0.15****************    0.04    0.01    0.02    0.01    0.02************************************    0.02
13 ACHNANTHES LANCEOLATA               0.23    0.46    0.81    0.49    0.49    0.37    0.48    0.62    0.38    0.26    0.14    0.13    0.22    0.09    0.15    0.11    0.12
14 ACHNANTHES LINEARIS                 1.48    0.19    0.17    0.04    0.05    0.13    0.13    0.28    0.06    0.02    0.03    0.06    0.10    0.01********    0.01    0.03
15 ACHNANTHES NOLLII               ********    0.13    0.03************************    0.17    0.16    0.03    0.02    0.01    0.03    0.07    0.05    0.04    0.11    0.01
16 ACHNANTHES PERAGALLI                0.04    0.01********************************    0.02    0.02****************    0.02****************    0.03********    0.01********
17 AMPHIPRORA PALUDOSA             ****************    0.04********************************************    0.02****************************************************************
18 AMPHIPLEURA PELLUCIDA               0.03    0.01    0.06    0.04    0.08    0.04    0.02    0.02    0.01    0.01********    0.01************************    0.01********
19 AMPHORA OVALIS                      0.28    0.06    0.38    0.34    0.60    0.21    0.28    0.23    0.17    0.06    0.15    0.19    0.17********    0.05    0.11    0.00
20 ASTERIONELLA FORMOSA            ********    0.02********    0.03    0.15    0.03    0.01********    0.35    0.30    0.54    0.40    0.19    0.30    0.49    0.78    1.17
21 COCCONEIS DISCULUS              ********    0.24    0.55    0.46    0.47    0.88    0.15    0.46    0.21    0.12    0.08    0.03    0.04    0.01    0.08    0.14    0.17
22 COCCONEIS PLACENTULA                0.19    0.10    0.21    0.77    0.47    0.32    0.85    0.43    0.99    0.55    0.43    0.20    0.33    0.25    0.18    0.24    0.17
23 COCCONEIS RUGOSA                    0.19    0.06****************************************    0.01    0.05    0.04    0.00********    0.01********    0.00    0.02    0.01
24 CYMBELLA CUSPIDATA                  0.13    0.04    0.01********    0.04    0.19    0.01********    0.01    0.02    0.02************************    0.00****************
25 CYMBELLA GRACILIS               ********    0.06    0.15    0.11    0.17    0.02    0.04********    0.01    0.03    0.00    0.02************************************    0.00
26 CYMBELLA LANCEOLATA                 0.01    0.08    0.11    0.01    0.12    0.06    0.09    0.10    0.05    0.04    0.04    0.02    0.01****************    0.04****************
27 CYMBELLA VENTRICOSA                 0.33    0.17    0.22    0.28    0.19[illegible] 0.25    0.11    0.12    0.11    0.09    0.07    0.10    0.00    0.06    0.03    0.04
28 CYMBELLA SINUATA                    0.04    0.15    0.22    0.42    0.46    0.47    0.39    0.41    0.13    0.15    0.14    0.05    0.16    0.02    0.03    0.02    0.11
29 CYMBELLA PROSTRATA              ************************************************************************************************    0.01********    0.01    0.02********
30 CYMATOPLEURA SOLEA              ****************    0.31****************    0.10    0.03    0.06    0.00    0.02    0.04    0.02************************************    0.02
31 DIATOMA ANCEPS                      0.02    0.01    0.01    0.06****************    0.04    0.10********    0.01    0.04    0.02    0.01    0.01    0.02********    0.01
32 DIATOMA HIEMALE                     0.04********    0.06********    0.01********    0.04    0.02****************    0.02    0.04    0.03********    0.04    0.71    0.03
33 DIATOMA VULGARE                 ****************************************************************************************************************************************
34 DIPLONEIS ELLIPTICA                 0.02********    0.01    0.12    0.12********    0.04    0.10    0.10    0.01    0.04    0.01    0.05    0.01********    0.01********
35 DIPLONEIS OCULATA               ****************    0.03    0.01********    0.43    0.23    0.09    0.17    0.14    0.02    0.02    0.06    0.02********    0.08********
36 DIPLONEIS FINNICA               ****************************************************************************************************************************************
37 EUNOTIA NAEGELII                ************************    0.01****************    0.01    0.07    0.04    0.02********    0.01    0.00    0.01************************    0.04
38 EUNOTIA TENELLA                     0.02    0.01********    0.06    0.03    0.04    0.03    0.05    0.03    0.04    0.03    0.05    0.02    0.01********    0.02    0.02
39 EUNOTIA TRIODON                 ************************************************************************    0.01****************************************************************
40 EUNOTIA PERPUSILLA              ********    0.06****************************************************************    0.31****************************************************
41 EUNOTIA PECTINALIS VENT.        ****************************************************************************************************    0.01********************************
42 EUNOTIA PECTINALIS              ************************************************************************************************************    0.01************************
43 EPITHEMIA SOREX                     0.65    0.15    0.46    0.28    0.36    0.16    0.33    0.31    0.91    0.14    0.21    0.14    0.08    0.01    0.10    0.08    0.08
44 EPITHEMIA TURGIDA               ****************    0.01    0.06****************    0.03    0.03    0.04    0.03    0.02************************    0.05    0.01********
45 EPITHEMIA ZEBRA                     0.39    0.17    0.10    0.15    0.04    0.17    0.11    0.24    0.16    0.15    0.13    0.08    0.03    0.09    0.01    0.07    0.10
46 EPITHEMIA ARGUS                 ****************************************************************************************************************************************
47 FRAGILARIA CROTONENSIS              9.83    9.90   11.20   18.04   33.03   31.27   32.50   41.83   59.09   42.35   44.51   46.41   50.43   54.37   62.31  119.47  188.58
48 FRAGILARIA INTERMEDIA           ********    1.50    4.95    4.67    3.54    4.93    2.08    3.08    1.94    0.23    0.03    0.14    0.09    0.04    0.06    0.21    0.03
49 FRAGILARIA PINNATA                 13.74    0.72    1.20    0.82    2.61    9.53    5.80    5.11    1.95    0.11    0.58    0.31    0.76    0.58    0.35    0.85    0.77
50 FRAGILARIA VAUCHERIAE           ****************************************    0.06    0.01    0.01    0.00    0.02    0.01    0.01    0.02    0.04    0.01    0.08    0.10
51 FRAGILARIA CONSTRUENS           ********    0.01    0.02    0.09    0.12********    0.05    0.05    0.04    0.04    0.00************************    0.00****************
52 FRAGILARIA LEPTOSTAURON         ************************************************    0.00****************************************************************************************
53 FRAGILARIA CAPUCINA             ****************************************************************************************************************************************
54 FRUSTULIA RHOMBOIDES            ************************    0.11****************    0.01    0.01    0.00****************************************************************
55 GOMPHONEMA ACUMINATUM               0.05    0.03********    0.10    0.17    0.02    0.04    0.03    0.12    0.01    0.07    0.02********    0.01****************    0.03
56 GOMPHONEMA PARVULUM                 0.23    0.04    0.34    0.06    0.13    0.30    0.19    0.12    0.15    0.13    0.02    0.07    0.04********    0.04    0.07    0.03
57 GOMPHONEMA CAPITATUM                0.04************************    0.11****************    0.02    0.02    0.01    0.02****************    0.01************************
58 GOMPHONEMA VENTRICOSUM          ****************************************************************************************************************************************
59 NANTZSCHIA AMPHIOXYS            ****************************************************************    0.01********    0.01****************************************************
60 GYROSIGMA ATTENUATUM            ********************************    0.04****************************************    0.02    0.00    0.01****************************************
61 HANNEA ARCUS                    ********    0.02    0.02****************************************************************************************************************    0.03
62 MASTOGLOIA SMITHII                  0.05********    0.03    0.01********    0.01    0.05    0.02    0.02    0.03    0.04    0.03    0.00    0.01    0.02    0.07********
63 MERIDION CIRCULARE                  0.08************************************************    0.07************************    0.01    0.01    0.01********************************    0.00
64 NAVICULA AURORA                     0.04********    0.21    0.10    0.08    0.06    0.04    0.04    0.03    0.03    0.03    0.05    0.01    0.03    0.01********    0.01
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                          LAKE TAHOE 1968-1969*****PHYTOPLANKTON******
                          ********************************************
                          AVERAGE NUMBER OF INDIVIDUALS PER ML

                           DATE=   11/ 9   17/ 9   26/ 9   15/10   19/10   27/10    2/11    1/12    7/12   22/12   16/ 1    1/ 2   15/ 2    2/ 3   15/ 3   30/ 3   13/ 4
                        SPEC.
 65  NAVICULA BACILLUM              0.15    0.04    0.13********    0.21    0.10    0.14    0.19    0.14    0.08    0.97    0.04********    0.01****************    0.05
 66  NAVICULA COCCONEIFORMIS    ********    0.02****************************************************************    0.01    0.10    0.03    0.00********    0.02    0.09
 67  NAVICULA EXIGUA                0.16    0.03    0.26    0.35    0.13    0.16    0.14    0.22    0.18    0.05    0.11    0.08    0.03    0.02    0.04    0.06    0.01
 68  NAVICULA FESTIVA           ************************    0.08    0.18    0.06    0.05    0.03    0.02********    0.06    0.06    0.03    0.01    0.04    0.03    0.02
 69  NAVICULA MUTICA            ********************************    0.04********    0.03************************    0.01********    0.01    0.05********    0.05    0.04
 70  NAVICULA PSEUDOSCUTIFORM.      0.18    0.13********    0.06    0.08    0.04    0.08    0.11    0.03    0.01****************    0.01****************    0.02    0.04
 71  NAVICULA PUPULA                0.17    0.11    0.32    0.61    0.73    0.33    0.50    0.28    0.28    0.08    0.15    0.08    0.07    0.01    0.00    0.13    0.10
 72  NAVICULA RADIOSA               0.54    0.52    1.10    1.47    1.91    1.86    1.28    1.22    0.91    0.49    0.33    0.21    0.37    0.09    0.10    0.20    0.16
 73  NAVICULA SCUTELLOIDES      ************************************************    0.00********************************************************************************
 74  NAVICULA CAPITATA          ********    0.08    0.06    0.12    0.18    0.40    0.07    0.07    0.11    0.03    0.07    0.06    0.05    0.01    0.06    0.02    0.00
 75  NAVICULA CUSPIDATA         ********************************************************************************************************************************************
 76  NAVICULA COSTULATA         ********************************************************************************************************************************************
 77  NEIDIUM HITCHCOCKII            0.04********    0.02****************    0.01    0.01********    0.01********    0.01************************************************
 78  NEIDIUM AFFINE             ************************    0.09    0.07********    0.01    0.02********    0.01    0.02************************************************
 79  NITZSCHIA FILLIFORMIS          0.29    0.04    0.18    0.22    0.38    0.40    0.68    0.73    0.30********    0.26    0.26    0.18    0.06    0.01    0.05    0.05
 80  NITZSCHIA AMPHIBIA             0.08    0.45    0.37    0.53    0.53    0.41    0.34    0.34    0.16********    0.34    0.34    0.25    0.19    0.13    0.25    0.76
 81  NITZSCHIA SINUATA          ********************************************************************************************************************************************
 82  NITZSCHIA PALEA            ********************************************************************************************************************************************
 83  OPEPHORA MARTYI            ********    2.64    3.15    4.72    4.44    7.29    4.01    2.37    0.99    0.40    0.07    0.31    0.60    0.08    0.13    0.15    0.00
 84  OPEPHORA AMERICANA         ********************************************************************************************************************************************
 85  PINNULARIA BICEPS              0.07********    0.08    0.05    0.06    0.01    0.05    0.05    0.03    0.02    0.01    0.04********    0.01    0.01    0.04********
 86  PINNULARIA AESTUARII       ********    0.03************************    0.02    0.03    0.01****************    0.03********    0.04    0.04************************
 87  PINNULARIA SUBCAPITATA     ********************************************************************************************************************************************
 88  PINNULARIA ARAUJENSIS      ********************************    0.04********    0.02****************    0.04****************************************************
 89  PINNULARIA RUPESTRIS       ************************************************************************    0.01************************    0.01************************
 90  RHOICOSPHENIA CURVATA      ********    0.02    0.02    0.01****************    0.03    0.11    0.04    0.02    0.01    0.05    0.01    0.04    0.00    0.02    0.03
 91  RHOPALODIA GIBBA               0.29    0.01****************    0.03    0.04    0.04    0.03    0.08    0.08    0.01    0.02    0.07    0.01********    0.02********
 92  STAURONEIS PHOENCENTERON   ********************************    0.06    0.02****************************************    0.01****************************************
 93  STAURONEIS SMITHII         ********    0.01    0.02****************    0.02    0.04    0.06    0.02****************    0.00    0.01    0.00********    0.04********
 94  STAURONEIS ANCEPS          ****************    0.01************************    0.02    0.01    0.01************************************************************************
 95  SURIRELLA OVATA            ****************    0.01    0.01********    0.06************************    0.01    0.03********    0.00********************************
 96  SYNEDRA AMPHICEPHALA           0.14    0.02    0.01********    0.01************************    0.01****************    0.01****************************************
 97  SYNEDRA MAZAMENSIS         ********    0.01    0.25    0.21    0.01    0.00    0.13    0.08    0.07    0.09    0.02    0.04    0.02    0.01    0.01    0.10    0.04
 98  SYNEDRA RADIANS            ************************************************************************    0.12****************************************************************
 99  SYNEDRA RUMPENS                0.04    0.04************************    0.02    0.04    0.01    0.01    0.01    0.00    0.06********    0.03    0.02    0.07********
100  SYNEDRA SOCIA                  0.04************************************************************************************************************************************
101  SYNEDRA ULNA                   0.11    0.01****************    0.04********    0.02    0.06    0.02    0.02****************    0.05    0.07    0.06    0.02    0.33
102  SYNEDRA INCISA             ********    0.11    0.17    0.08    0.10    0.10    0.04    0.12    0.08****************    0.03    0.00    0.01    0.01    0.03    0.12
103  TABELLARIA FENESTRATA      ********    0.04****************************************************************    0.01****************************************************************
104  TABELLARIA FLOCCULOSA      ************************************************    0.01********    0.02    0.01****************************************************************
105  TETRACYCLUS EMARGINATUS        0.02    0.04****************************************************************    0.01****************************************************************
106  TETRACYCLUS LACUSTRIS      ********    0.01********************************    0.01    0.02********************************    0.04    0.01********    0.02********
107  DIATOMELLA BALFOURIANA     ************************************************    0.03    0.01********    0.03****************************************    0.04    0.01********
108  ACTINOCYCLUS EHRENBERGII   ********************************    0.06****************************************************************************************************
109  CALONEIS FENZLII           ********************************************************************************************************************************************
110  CALONEIS SPECIOSA          ********************************************************************************************************************************************
111  BIDDULPHIA AURITA          ********************************************************************************************************************************************
112  GOMPHONEIS HERCULEANA      ********************************************************************************************************************************************
113  ELAKATOTHRIX GELATINOSA        0.71****************************************************************************************    0.08    0.01****************************************
114  SCENEDESMUS QUADRICAUDA    ********************************    0.06************************************************************    0.01************************************************
115  SPHAEROCYSTIS SCHROETERI       1.33********    0.02    0.19    0.08    0.17    0.54    0.35    0.34    0.13    0.42    0.09    0.16    0.11    0.12    0.05    0.07
116  STAURASTRUM PARADOXUM      ************************************************    0.02****************    0.02    0.07    0.32    0.03    0.01************************    0.07
117  BOTRYOCOCCUS BRAUNII       ********************************************************************************************************************************************
118  OOCYSTIS NAEGELII          ********************************************************************************************************************************************
119  PEDIASTRUM KAWRAISKYI      ********************************************************************************************************************************************
120  ULOTHRIX AEQUALIS          ********************************************************************************************************************************************
121  ANABAENA SP.               ********************************************************************************************************************************************
122  MERISMOPEDIA ELEGANS       ********************************************************************************    0.02********************************************************
123  POLYCYSTIS AERUGINOSA      ********************************************************************************************************************************************
124  DINOBRYON SERTULARIA           1.00****************    1.19    0.29    1.72    0.39    4.50    2.95    1.84    3.32    1.41    2.04    0.23********    1.43    4.37
125  KEPHYRION OVUM                 4.40************************************************************************************************    0.07    0.59    0.80    0.16    0.96
126  MALLOMONAS                 ********************************************************************************************************************************************
127  PERIDINIUM SP.                12.95    0.63    1.44    0.90    2.67    4.46    0.74    0.84    0.63    0.37    0.11    0.14    0.04********    0.04    0.02********
128  CERATIUM HIRUNDINELLA      ****************************************************************************************************************    0.00************************
129  CRYPTOMONAS REFLEXA        ********************************************************************************************************************************************
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LAKE TAHOE 1969******PHYTOPLANKTON*****

AVERAGE NUMBER OF INDIVIDUALS PER ML

	SPEC. / DATE	25/ 4	9/ 5	23/ 5	7/ 6	20/ 6	1/ 7	8/ 7	19/ 7	22/ 7	28/ 7	30/ 7	5/ 8	20/ 8	28/ 8	3/ 9	9/ 9	15/ 9
1	CYCLOTELLA ANTIQUA				0.08		0.01			0.08		0.03		0.01	0.07		0.01	0.01
2	CYCLOTELLA BODANICA	2.63	2.54	1.55	2.19	1.53	1.12	1.57	0.56	3.39	0.32	1.01	0.04	0.95	6.30	1.24	1.70	1.59
3	CYCLOTELLA OCELLATA	0.04	0.19	0.08	0.28	0.34	0.39	0.09	0.29	4.83		1.08		0.28	51.82	0.01		0.05
4	CYCLOTELLA STELLIGERA	0.08						0.00						0.00				
5	MELOSIRA CRENULATA	18.88	15.79	12.21	8.46	7.22	5.28	2.59	1.06	18.74	0.28	5.59	0.00	2.14	28.79	0.86	0.79	7.09
6	MELOSIRA GRANULATA				0.01				0.00						0.61			0.03
7	MELOSIRA VARIANS	0.07																
8	MELOSIRA UNDULATA																	
9	STEPHANODISCUS ASTREA	5.93	3.35	1.93	2.56	2.26	0.98	0.25	0.93	3.79	0.06	1.49	0.01	0.73	3.77	0.05	1.61	1.78
10	ACHNANTHES CLEVEI	0.17	0.16	0.08	0.09	0.10	0.05	0.01	0.03	0.47			0.01	0.01	0.39	0.04	0.08	
11	ACHNANTHES EXIGUA				0.01	0.01	0.00		0.02		0.03	0.01	0.00	0.02	0.00			0.02
12	ACHNANTHES FLEXELLA		0.02		0.00		0.02	0.00		0.04		0.15			0.09	0.02		0.02
13	ACHNANTHES LANCEOLATA	0.47	0.08	0.07	0.14	0.23	0.17	0.11	0.17	0.22	0.07	0.27	0.01	0.02	0.62	0.06	0.19	0.12
14	ACHNANTHES LINEARIS	0.05	0.04		0.05	0.02	0.04	0.01	0.10		0.00	0.01	0.00					
15	ACHNANTHES NOLLII	0.08																
16	ACHNANTHES PERAGALLI				0.02	0.02	0.01		0.01	0.01	0.09	0.12			0.05	0.01	0.01	0.02
17	AMPHIPRORA PALUDOSA																	
18	AMPHIPLEURA PELLUCIDA	0.01					0.01			0.02	0.01							
19	AMPHORA OVALIS	0.13	0.02	0.05	0.03	0.00	0.04	0.01	0.03	0.00	0.02	0.12		0.07	0.10		0.03	0.09
20	ASTERIONELLA FORMOSA	0.95	0.89	0.01	0.37	0.87	0.02	0.00	0.07	0.11	0.03	0.11	0.48	0.10	0.20	0.01	0.04	0.13
21	COCCONEIS DISCULUS	0.03	0.05	0.02	0.03	0.00	0.05	0.05	0.00	0.06		0.01		0.04	0.24	0.01	0.01	
22	COCCONEIS PLACENTULA	0.21	0.17	0.17	0.19	0.06	0.18	0.07	0.10	0.59	0.02	0.22	0.00	0.15	0.70	0.05	0.17	1.04
23	COCCONEIS RUGOSA	0.01							0.01						0.04		0.01	0.01
24	CYMBELLA CUSPIDATA			0.01			0.01		0.02	0.06	0.01							0.03
25	CYMBELLA GRACILIS	0.01				0.01	0.03	0.01	0.01	0.06		0.01	0.00		0.03		0.01	
26	CYMBELLA LANCEOLATA	0.04			0.03		0.01		0.00	0.28	0.01	0.02			0.01			0.05
27	CYMBELLA VENTRICOSA	0.08	0.18	1.02	0.17	0.20	0.28	0.04	0.21	0.73	0.02	0.28	0.04	0.03	0.99	0.07	0.28	0.31
28	CYMBELLA SINUATA	0.11	0.05	0.05	0.02	0.06	0.16	0.07	0.09	0.14	0.00	0.34	0.00	0.04	0.13	0.04	0.03	0.12
29	CYMBELLA PROSTRATA			0.01	0.00				0.01	0.04		0.02			0.01			
30	CYMATOPLEURA SOLEA						0.01		0.02									
31	DIATOMA ANCEPS	0.01		0.01	0.02	0.02	0.04		0.01		0.00	0.02	0.01		0.05	0.02	0.02	0.05
32	DIATOMA HIEMALE	0.24	0.12	0.04	0.02			0.07	0.06					0.03	0.04		0.01	
33	DIATOMA VULGARE																	0.45
34	DIPLONEIS ELLIPTICA			0.01	0.01	0.02	0.05	0.07		0.00		0.02			0.07	0.01	0.08	0.08
35	DIPLONEIS OCULATA	0.10	0.05	0.03	0.07	0.02	0.05		0.03	0.04					0.03	0.01	0.00	0.02
36	DIPLONEIS FINNICA									0.05								
37	EUNOTIA NAEGELII			0.03			0.01			0.04	0.01						0.01	0.03
38	EUNOTIA TENELLA	0.01		0.01	0.02	0.07		0.01	0.02	0.12				0.01	0.18			0.06
39	EUNOTIA TRIODON																	
40	EUNOTIA PERPUSILLA							0.01										0.01
41	EUNOTIA PECTINALIS VENT.																	
42	EUNOTIA PECTINALIS									0.04		0.03				0.01		
43	EPITHEMIA SOREX	0.06	0.11	0.05	0.01	0.00		0.09	0.02	0.68	0.01	0.03		0.13	0.51	0.01	0.03	0.06
44	EPITHEMIA TURGIDA					0.04	0.03		0.00	0.32		0.08			0.03			0.10
45	EPITHEMIA ZEBRA		0.05	0.08	0.04	0.16	0.17	0.03	0.14	0.63	0.04	0.19		0.04	0.29	0.42	0.59	1.10
46	EPITHEMIA ARGUS																	
47	FRAGILARIA CROTONENSIS	182.69	262.37	120.24	231.77	401.69	104.20	77.37	63.71	81.40	18.53	91.08	29.21	71.57	90.89	35.47	51.23	47.86
48	FRAGILARIA INTERMEDIA	0.80			0.08			0.17	0.19		0.00					0.06	0.05	0.13
49	FRAGILARIA PINNATA	0.30	0.44	0.18	1.95	1.40	1.17	0.34	1.31	1.00	0.40	0.01		0.04	0.39	2.34	2.40	0.09
50	FRAGILARIA VAUCHERIAE	0.03	0.06		0.03	0.04	0.01	0.00	0.01	0.01	0.00		0.00	0.02			0.00	0.00
51	FRAGILARIA CONSTRUENS	0.00		0.02		0.00		0.03	0.01	0.04		0.01			0.40		0.10	0.01
52	FRAGILARIA LEPTOSTAURON									0.08								
53	FRAGILARIA CAPUCINA																	
54	FRUSTULIA RHOMBOIDES				0.01												0.02	0.03
55	GOMPHONEMA ACUMINATUM	0.00	0.05	0.01	0.04		0.04	0.07	0.04		0.01	0.01		0.02	0.07	0.03		0.01
56	GOMPHONEMA PARVULUM	0.11	0.04	0.02	0.14	0.10	0.00	0.10	0.08	0.37	0.02	0.07	0.01	0.03	0.08	0.13	0.20	0.19
57	GOMPHONEMA CAPITATUM		0.05	0.01	0.04	0.02	0.05	0.01	0.01	0.03					0.04	0.01	0.05	0.02
58	GOMPHONEMA VENTRICOSUM																	
59	HANTZSCHIA AMPHIOXYS								0.01		0.09					0.01		0.03
60	GYROSIGMA ATTENUATUM	0.01	0.01									0.08						
61	HANNEA ARCUS	0.01		0.08	0.02	0.05	0.01	0.01	0.03			0.01	0.00			0.01		
62	MASTOGLOIA SMITHII	0.04			0.02	0.01	0.02		0.02		0.00	0.10	0.01	0.04	0.07	0.05	0.07	0.15
63	MERIDION CIRCULARE			0.01	0.08	0.00	0.01	0.01		0.03		0.02			0.06		0.01	0.01
64	NAVICULA AURORA	0.01	0.03	0.01	0.04	0.05	0.03	0.01	0.02	0.23			0.00	0.01	0.18	0.04	0.05	0.18

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                                  LAKE TAHOE 1969*****PHYTOPLANKTON******
                                  ***************************************
                                  AVERAGE NUMBER OF INDIVIDUALS PER ML

                                DATE=   25/ 4    9/ 5   23/ 5    7/ 6   20/ 6    1/ 7    8/ 7   15/ 7   22/ 7   24/ 7   30/ 7    5/ 8   20/ 8   28/ 8    3/ 9    9/ 9   15/ 9
                              SPEC.
 65  NAVICULA BACILLUM              ********    0.07    0.04    0.04    0.05********    0.04    0.13    0.03    0.04    0.01    0.00    0.01    0.04    0.02    0.09    0.03
 66  NAVICULA COCCONEIFORMIS            0.03    0.14    0.12    0.21    0.20    0.26    0.03    0.24    0.05    0.01    0.04    0.01    0.07    0.05    0.09    0.05    0.14
 67  NAVICULA EXIGUA                    0.01    0.05    0.04    0.05    0.08    0.05    0.04    0.08    0.04********    0.01********    0.01********    0.05    0.07    0.14
 68  NAVICULA FESTIVA               ********************************    0.00********    0.01****************************************    0.04****************    0.01********
 69  NAVICULA MUTICA                    0.07********    0.02****************    0.04    0.00    0.01********    0.00    0.02    0.00    0.00    0.04    0.01    0.04    0.01
 70  NAVICULA PSEUDOSCUTIFORM.          0.02****************    0.07    0.01    0.10    0.01    0.09    0.02    0.00    0.05****************    0.12********    0.09    0.10
 71  NAVICULA PUPULA                    0.20    0.12    0.01    0.11    0.01    0.10    0.00    0.14    0.02    0.07    0.07    0.02    0.00    0.05    0.06    0.13    0.22
 72  NAVICULA RADIOSA                   0.27    0.05    0.09    0.04    0.06    0.19    0.07    0.20    0.11    0.04    0.04    0.01    0.04    0.21    0.04    0.23    0.36
 73  NAVICULA SCUTELLOIDES          ********************************************************    0.00    0.00****************************************************************    0.01
 74  NAVICULA CAPITATA                  0.04****************    0.00    0.01    0.00    0.01    0.02    0.01********    0.01********    0.01    0.02    0.01    0.01********
 75  NAVICULA CUSPIDATA             ****************************************************************************************************************    0.04****************    0.02
 76  NAVICULA COSTULATA             ********    0.01********    0.02************************    0.02************************************************************************
 77  NEIDIUM HITCHCOCKII            ****************************************************************    0.00********************************************************    0.03
 78  NEIDIUM AFFINE                 ************************    0.02************************    0.01    0.00    0.01************************************************    0.00
 79  NITZSCHIA FILIFORMIS               1.08    0.72    0.04    0.05    0.06    0.03    0.09    0.10    0.04********    0.01********    0.17    0.27********    0.06    0.06
 80  NITZSCHIA AMPHIBIA                 0.54    0.14    0.02    0.11    0.04    0.11    0.17    0.06    0.03********    0.04********    0.02    0.04    0.01    0.04    0.06
 81  NITZSCHIA SINUATA              ********************************************************************************************************************************    0.00
 82  NITZSCHIA PALEA                ****************************************************************************************************************************************
 83  OPEPHORA MARTYI                    0.29    0.02    0.01    0.04    0.05    0.08    0.14    0.11    0.51********    0.08********    0.07    0.80********    0.06    0.02
 84  OPEPHORA AMERICANA             ********************************    0.00    0.03****************    0.04************************    0.01    0.14************************
 85  PINNULARIA BICEPS              ********    0.03    0.01    0.01********    0.03********    0.03    0.02********    0.04********    0.00    0.05********    0.01    0.03
 86  PINNULARIA AESTUARII           ************************    0.01********************************    0.03********************************************************************
 87  PINNULARIA SUBCAPITATA         ********************************************************    0.02****************************************************************************
 88  PINNULARIA BRAUJENSIS          ****************************************************************    0.02********************************************************************
 89  PINNULARIA RUPESTRIS           ****************    0.02****************************************    0.02********************************************************************
 90  RHOICOSPHENIA CURVATA          ********    0.03********    0.04****************    0.00    0.00    0.01********************************************************    0.01    0.03
 91  RHOPALODIA GIBBA                   0.01    0.03    0.02    0.01********    0.01********    0.03    0.04    0.02    0.32********    0.07    0.04    0.09    0.08    0.13
 92  STAURONEIS PHOENICENTERON      ****************    0.01    0.01    0.02************************************************************************************************
 93  STAURONEIS SMITHII             ********************************    0.01    0.01********************************    0.00************************************************    0.01
 94  STAURONEIS ANCEPS              ****************************************************************************************************    0.01********    0.01    0.01    0.03
 95  SURIRELLA OVATA                ****************************************    0.01****************************************************************    0.01****************
 96  SYNEDRA AMPHICEPHALA               0.04********************************************************    0.01************************    0.00********************************
 97  SYNEDRA MAZAMENSIS                 0.11    0.17********    0.12    0.07    0.02    0.04    0.14********    0.00********    0.00********    0.04************************
 98  SYNEDRA RADIANS                ************************************************************************   33.42********   28.46****************************************
 99  SYNEDRA RUMPENS                    0.04********    0.03    0.01********    0.02********    0.02********    0.00    0.09************************    0.00    0.04    0.02
100  SYNEDRA SOCIA                  ****************************************************************************************************************************************
101  SYNEDRA ULNA                       0.14    0.02********    0.01    0.06    0.04    0.01    0.03    0.02    0.01    0.07    0.00    0.00********    0.03********    0.06
102  SYNEDRA INCISA                     0.17    0.02********    0.01    0.03********    0.09    0.01    0.01********    0.03********    0.06    0.05********    0.01    0.01
103  TABELLARIA FENESTRATA          ****************************************************************    0.04********************************************************    0.00
104  TABELLARIA FLOCCULOSA          ************************    0.01    0.00****************************************    0.01    0.00****************************************
105  TETRACYCLUS EMARGINATUS        ********************************    0.01********************************    0.11    0.01************************************************    0.01
106  TETRACYCLUS LACUSTRIS          ************************    0.02    0.04********************************    0.23********    0.04********    0.00    0.02************************
107  DIATOMELLA BALFOURIANA         ********************************************************    0.01****************    0.23****************    0.02    0.01****************
108  ACTINOCYCLUS EHRENBERGII       ****************************************************************    0.03************************    0.02    0.01****************    0.02
109  CALONEIS FENZLII               ********************************************************    0.03****************************************************************************
110  CALONEIS SPECIOSA              ****************************************************************************************************************************************
111  BIDDULPHIA AURITA              ********************************************************************************************************************************    0.02
112  GOMPHONEIS HERCULEANA          ****************************************************************************************************************************************
113  FLAKALOTHRIX GELATINOSA            0.02********************************************************************************************************************************
114  SCENEDESMUS QUADRICAUDA            0.02********************************************************************************************************************************
115  SPHAEROCYSTIS SCHROETERI           0.20    0.04********    0.06********    0.04    0.17    0.01****************    0.05********    0.07****************************************
116  STAURASTRUM PARADOXUM          ********    0.05    0.06    0.10    0.11    0.09    0.07    0.02****************    0.19********    0.10    0.11    0.19    0.13    0.08
117  BOTRYOCOCCUS BRAUNII           ****************************************************************************************************************************************
118  OOCYSTIS NAEGELII              ****************************************************************************************************************************************
119  PEDIASTRUM KAWRAISKYI          ****************************************************************************************************************************************
120  ULOTHRIX AEQUALIS              ****************************************************************************************************************************************
121  ANABAENA SP.                       0.04********************************************************    0.01************************************************    0.02************************
122  MERISMOPEDIA ELEGANS           ****************************************************************************************************************************************
123  POLYCYSTIS AERUGINOSA              0.09********************************************************************************************************************************
124  DINOBRYON SERTULARIA           ********    0.07********    0.10    0.08    0.07    5.24    0.05********   21.42    0.39    0.29    0.45    0.34****************    2.58
125  KEPHYRION OVUM                 ********************************    0.00********************************************************    0.10    0.19************************
126  MALLOMONAS                     ****************************************************************************************************************************************
127  PERIDINIUM SP.                     0.27    0.67    0.01    0.39    0.78    0.69    1.09    0.89********    0.01    0.06    0.04    0.11    0.24************************
128  CERATIUM HIRUNDINELLA          ************************************************    0.01****************************************************************************************
129  CRYPTOMONAS REFLEXA            ****************************************************************************************************************************************
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LAKE TAHOE 1969-1970*****PHYTOPLANKTON*****
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AVERAGE NUMBER OF INDIVIDUALS PER ML

	SPEC. \ DATE	24/ 9	10/10	22/10	28/10	12/11	23/11	5/12	14/12	26/12	6/ 1	19/ 1	30/ 1	10/ 2	23/ 2	28/ 2	10/ 3	23/ 3
1	CYCLOTELLA ANTIQUA	0.01			0.00					0.07		0.08	0.05	0.02			0.04	
2	CYCLOTELLA BODANICA	1.99	1.69	2.02	2.49	4.44	1.80	0.94	2.61	2.19	1.79	[illegible]	13.37	12.93	3.74	2.44	2.26	1.74
3	CYCLOTELLA OCELLATA	4.88			0.04													
4	CYCLOTELLA STELLIGERA																	
5	MELOSIRA CRENULATA	16.30	1.73	9.48	13.83	13.45	6.53	0.85	9.02	3.50	3.26	195.33	27.40	41.61	19.16	14.57	10.87	6.90
6	MELOSIRA GRANULATA		0.00	0.00		0.05	0.04					0.02	0.04					
7	MELOSIRA VARIANS																	0.04
8	MELOSIRA UNDULATA	0.11	0.13	0.02	0.04		0.14										0.01	
9	STEPHANODISCUS ASTREA	1.92	1.23	2.32	2.13	3.15	1.40	0.58	2.57	1.50	1.02	4.24	3.58	2.00	1.42	1.58	1.63	2.24
10	ACHNANTHES CLEVEI	0.15	0.01	0.00		0.08					0.01	0.02			0.03			
11	ACHNANTHES EXIGUA		0.01	0.00							0.02							
12	ACHNANTHES FLEXELLA	0.01	0.01	0.01		0.07	0.01		0.01				0.05					
13	ACHNANTHES LANCEOLATA	0.11	0.19	0.22	0.22	0.39	0.13	0.11	0.14	0.12	0.05	0.33	0.22	0.27	0.07	0.11	0.03	0.05
14	ACHNANTHES LINEARIS	0.02			0.02	0.02												
15	ACHNANTHES MOLLTI	0.03															0.02	
16	ACHNANTHES PERAGALLI	0.02		0.03	0.00	0.01	0.02						0.04	0.05		0.02		
17	AMPHIPRORA PALUDOSA																	
18	AMPHIPLEURA PELLUCIDA	0.01		0.02	0.01	0.00	0.02		0.01									
19	AMPHORA OVALIS	0.03	0.04	0.08	0.13	0.12	0.04	0.00	0.01	0.03	0.04	0.03	0.00	0.07		0.01		0.02
20	ASTERIONELLA FORMOSA	0.44	0.05	0.22	0.24	0.62	1.99	2.07	5.35	4.16	4.63	4.61	9.12	14.02	13.85	10.19	17.30	22.24
21	COCCONEIS DISCULUS	0.00																0.05
22	COCCONEIS PLACENTULA	0.29	0.31	0.58	0.61	0.22	0.29		0.41	0.27	0.09	1.84	0.83	0.55	0.18	0.38	0.26	0.24
23	COCCONEIS RUGOSA	0.04	0.01	0.03	0.05	0.02	0.02		0.02		0.01	0.13	0.04	0.01		0.02		
24	CYMBELLA CUSPIDATA	0.02			0.02					0.00	0.02	0.04						
25	CYMBELLA GRACILIS	0.03	0.01														0.02	
26	CYMBELLA LANCEOLATA	0.04	0.31	0.12	0.07	0.05	0.11		0.08	0.07	0.02	0.07	0.05	0.15	0.04	0.04		
27	CYMBELLA VENTRICOSA	0.44	0.28	0.59	0.63	0.30	0.51	0.03	0.53	0.09	0.19	2.39	0.38	0.86	0.52	0.21	0.05	0.03
28	CYMBELLA SINUATA	0.15	0.08	0.09	0.03	0.14		0.01	0.05	0.10	0.01	0.14	0.07	0.06	0.05	0.02	0.05	0.06
29	CYMBELLA PROSTRATA		0.00	0.06	0.01									0.01		0.02		
30	CYMATOPLEURA SOLEA	0.04																0.01
31	DIATOMA ANCEPS	0.01	0.03	0.01	0.04					0.04	0.07					0.01	0.02	
32	DIATOMA HIEMALE	0.01	0.05	0.03	0.02						0.01	0.09		0.04	0.04		0.08	0.01
33	DIATOMA VULGARE				0.04	0.14					0.02			0.04	0.01			
34	DIPLONEIS ELLIPTICA	0.02	0.06	0.02	0.04	0.10						0.03	0.03	0.06	0.02	0.04		
35	DIPLONEIS OCULATA	0.01	0.03	0.07	0.11	0.22	0.02	0.05	0.05	0.04	0.00	0.01			0.05	0.04	0.02	0.04
36	DIPLONEIS FINNICA				0.02					0.04					0.04			
37	EUNOTIA NAEGELII	0.01		0.01		0.03					0.02			0.02				
38	EUNOTIA TENELLA	0.01	0.03	0.07	0.03					0.03	0.01	0.04		0.02	0.01	0.04	0.04	0.02
39	EUNOTIA TRIODON																	
40	EUNOTIA PERPUSILLA		0.00									0.02						
41	EUNOTIA PECTINALIS VENT.																	
42	EUNOTIA PECTINALIS				0.00													
43	EPITHEMIA SOREX	0.34	0.01										0.05			0.02	0.03	
44	EPITHEMIA TURGIDA	0.05	0.02	0.07	0.17	0.07	0.04	0.04	0.04	0.07		0.09	0.03	0.02	0.04			
45	EPITHEMIA ZEBRA	0.17	0.46	0.52	0.45	0.46	0.23	0.24	0.42	0.17	0.22	0.94	0.27	0.38	0.41	0.16	0.05	0.10
46	EPITHEMIA ARGUS																	
47	FRAGILARIA CROTONENSIS	84.49	47.42	51.88	39.95	19.31	15.91	25.24	50.18	44.95	39.21	45.97	50.16	52.67	67.72	61.28	85.37	89.16
48	FRAGILARIA INTERMEDIA	0.10	0.19		0.00													
49	FRAGILARIA PINNATA	2.84	0.07	0.41	0.23	0.49	0.91	0.02	0.51				0.07	0.54		0.20	0.02	1.24
50	FRAGILARIA VAUCHERIAE	0.01			0.04	0.04				0.04					0.04			
51	FRAGILARIA CONSTRUENS	0.03	0.00	0.05	0.04							0.01		0.02				
52	FRAGILARIA LEPTOSTAURON											0.02						
53	FRAGILARIA CAPUCINA																	
54	FRUSTULIA RHOMBOIDES	0.02			0.00		0.04		0.04					0.03				
55	GOMPHONEMA ACUMINATUM		0.02	0.01					0.05					0.03		0.02		0.02
56	GOMPHONEMA PARVULUM	0.09	0.17	0.07	0.15	0.24	0.05	0.02	0.01	0.01	0.03	0.33	0.14	0.13		0.03	0.08	0.04
57	GOMPHONEMA CAPITATUM	0.01	0.02	0.03		0.02				0.01		0.02	0.02	0.01	0.04	0.05		0.01
58	GOMPHONEMA VENTRICOSUM																	
59	HANTZSCHIA AMPHIOXYS		0.00			0.04												
60	GYROSIGMA ATTENUATUM			0.01								0.02				0.02		
61	HANNEA ARCUS		0.03						0.01		0.03					0.05		
62	MASTOGLOIA SMITHII	0.06	0.09	0.10	0.04	0.06	0.02	0.03	0.13		0.02		0.05	0.04	0.02	0.05	0.09	0.04
63	MERIDION CIRCULARE	0.04	0.06	0.01	0.02							0.06			0.01	0.07	0.01	0.03
64	NAVICULA AURORA	0.05	0.09	0.09	0.03	0.05	0.01	0.03	0.05		0.01	0.24	0.14	0.03	0.20	0.09	0.03	0.04

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                                LAKE TAHOE 1969-1970*****PHYTOPLANKTON*****
                                *******************************************
                                AVERAGE NUMBER OF INDIVIDUALS PER ML

                              DATE*  24/ 9  10/10  22/10  28/10  12/11  23/11   5/12  14/12  26/12   8/ 1  19/ 1  30/ 1  10/ 2  23/ 2  28/ 2  10/ 3  23/ 3
                           SPEC.
 65  NAVICULA BACILLUM               0.01   0.08   0.07   0.02   0.11   0.09   0.02   0.13   0.12*******   0.05*******   0.02   0.03   0.04*******   0.05
 66  NAVICULA COCCONEIFORMIS         0.12   0.24   0.12   0.23   0.17   0.11   0.10   0.11   0.03   0.02   0.06   0.02   0.09   0.01   0.09*******   0.08
 67  NAVICULA EXIGUA                 0.03   0.07   0.08   0.05   0.17   0.00   0.01   0.03   0.04   0.04   0.04   0.05   0.02   0.02   0.02   0.00   0.02
 68  NAVICULA FESTIVA                0.03***************************************************************   0.07******************************************
 69  NAVICULA MUTICA            *******   0.01   0.01   0.01   0.01**************   0.02**************   0.11   0.03   0.04   0.02*********************
 70  NAVICULA PSEUDOSCUTIFORM.       0.03   0.03   0.07   0.09   0.11   0.08*******   0.06*******   0.01   0.10   0.09   0.07   0.05*******   0.03   0.00
 71  NAVICULA PUPULA                 0.03   0.05   0.16   0.15   0.25   0.10   0.09   0.08   0.01   0.03   0.09   0.09   0.05*********************   0.05
 72  NAVICULA RADIOSA                0.20   0.22   0.37   0.18   0.21   0.14   0.04   0.03   0.10   0.08   0.12   0.03   0.01   0.02   0.11   0.08   0.07
 73  NAVICULA SCUTELLOIDES      **************   0.01**************************************************************************************************
 74  NAVICULA CAPITATA               0.01*********************   0.05   0.01*******   0.04***************************************************************
 75  NAVICULA CUSPIDATA         *********************   0.01*******************************************************************************************
 76  NAVICULA COSTULATA         *********************   0.02   0.01************************************************************************************
 77  NEIDIUM HITCHCOCKII        ***********************************   0.02*****************************************************************************
 78  NEIDIUM AFFINE             **************   0.01   0.01***************************************************************   0.02*********************
 79  NITZSCHIA FILIFORMIS            0.01   0.15   0.03   0.09   0.05**************   0.02   0.05   0.02   0.05   0.05   0.01*******   0.05   0.02   0.05
 80  NITZSCHIA AMPHIBIA              0.02   0.36   0.03   0.03   0.05**************   0.02   0.05   0.02   0.02   0.04   0.03*******   0.02   0.00   0.03
 81  NITZSCHIA SINUATA          ************************************************************************************   0.02****************************
 82  NITZSCHIA PALEA            ***********************************************************************************************************************
 83  PEPHORA MARTYI                  0.28   0.09*******   0.00   0.09   0.05*****************************************************************************
 84  PEPHORA AMERICANA               0.07**************   0.00   0.02*********************   0.00***********************************   0.02**************
 85  PINNULARIA BICEPS               0.04   0.01   0.01   0.03   0.04   0.02*******   0.01   0.00   0.01   0.00   0.02*******   0.01*********************
 86  PINNULARIA AESTUARII            0.04   0.02**************   0.01   0.01***********************************************************************************
 87  PINNULARIA SUBCAPITATA          0.04*********************   0.02******************************************************************************************
 88  PINNULARIA ABAUJENSIS      **************   0.03*************************************************   0.02   0.01***********************************
 89  PINNULARIA RUPESTRIS            0.03*******   0.00*****************************************************************************************************
 90  RHOICOSPHENIA CURVATA      **************   0.02****************************   0.01*******************************************   0.02**************
 91  RHOPALODIA GIBBA                0.10   0.11   0.10   0.05   0.10   0.03*******   0.02   0.02   0.05   0.12   0.02   0.03*******   0.02   0.04   0.04
 92  STAURONEIS PHOENICENTERON  *******   0.01   0.02**********************************************************************************************************
 93  STAURONEIS SMITHII         *******   0.00*************************************************************   0.01***********************************
 94  STAURONEIS ANCEPS               0.01   0.02   0.00**************   0.02***********************************************************************************
 95  SURIRELLA OVATA                 0.01   0.02*******   0.01********************************************************   0.03****************************
 96  SYNEDRA AMPHICEPHALA       ***********************************************************************************************************************
 97  SYNEDRA MAZAMAENSIS        *******   0.01**********************************************************************   0.01*********************
 98  SYNEDRA RADIANS            ***********************************************************************************************************************
 99  SYNEDRA RUMPENS                 0.03*******   0.02   0.01****************************   0.07*************************************************   0.04
100  SYNEDRA SOCIA              ***********************************************************************************************************************
101  SYNEDRA ULNA                    0.01*******   0.11   0.19   0.07   0.09   0.01   0.04   0.01   0.03   0.04   0.07   0.00   0.04**************   0.04
102  SYNEDRA INCISA                  0.03   0.00*******   0.00******************************************************************************   0.02*******
103  TABELLARIA FENESTRATA      ***********************************************************************************************************************
104  TABELLARIA FLOCCULOSA      ****************************   0.01   0.02   0.01*******************************************   0.04   0.09**************
105  TETRACYCLUS EMARGINATUS         0.09***********************************   0.01*******   0.02**************   0.05**************   0.02   0.04**************
106  TETRACYCLUS LACUSTRIS      *******************************************************************************************   0.01   0.02**************
107  DIATOMELLA BALFOURIANA     *************************************************   0.04**************   0.03******************************************
108  ACTINOCYCLUS EHRENBERGII   **************   0.06   0.01*****************************************************************************   0.01*******
109  CALONEIS FENZLII           *******   0.01*****************************************************************************************************
110  CALONEIS SPECIOSA          *********************   0.01*********************   0.00**************   0.01******************************************
111  BIDDULPHIA AURITA          ***********************************************************************************************************************
112  GOMPHONEIS HERCULEANA      ***********************************************************************************************************************
113  ELAKATOTHRIX GELATINOSA    ***********************************************************************************************************************
114  SCENEDESMUS QUADRICAUDA         0.02*********************   0.03**************************************************************************************
115  SPHAEROCYSTIS SCHROETERI        0.11   0.02   0.01**************   0.08*******   0.46   0.13   0.09   0.29   0.16   0.33   0.12   0.27   0.29   0.54
116  STAURASTRUM PARADOXUM           0.20   0.17   0.04   0.04   0.04**************   0.07   0.14   0.02   0.07   0.04   0.04   0.02   0.09   0.07   0.07
117  BOTRYOCOCCUS BRAUNII       *********************   0.04*********************   0.12***************************************************************
118  OOCYSTIS NAEGELII          ****************************   0.12*******************************************************************************************
119  PEDIASTRUM KAWRAISKYI      ***********************************************************************************************************************
120  ULOTHRIX AEQUALIS          ***********************************************************************************************************************
121  ANABAENA SP.               ***********************************************************************************************************************
122  MERISMOPEDIA ELEGANS       ***********************************************************************************************************************
123  POLYCYSTIS AERUGINOSA      *************************************************   0.02*************************************************   0.06*******
124  DINOBRYON SERTULARIA       *******   0.13   0.03   0.02   0.11   0.30   0.04   0.27   0.10   0.07**************   0.07*******   0.19   0.09   0.95
125  KEPHYRION OVUM             ***********************************************************************************************************************
126  MALLOMONAS                 ***********************************************************************************************************************
127  PERIDINIUM SP.                  0.08**************   0.12   0.09*******   0.00   0.02*******   0.08   0.01   0.24   0.33   0.05   0.22   0.33   0.08
128  CERATIUM HIRUNDINELLA      ***********************************************************************************************************************
129  CRYPTOMONAS REFLEXA        ***********************************************************************************************************************
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LAKE TAHOE 1970-1971*****PHYTOPLANKTON*****

AVERAGE NUMBER OF INDIVIDUALS PER ML

	SPEC. / DATE*	2/ 4	15/ 4	2/ 5	13/ 5	16/ 6	24/ 8	2/ 9	21/ 1	3/ 2	12/ 2	22/ 2	23/ 4	5/10
1	CYCLOTELLA ANTIQUA	0.03	0.01	0.02	0.02	0.00		0.01						
2	CYCLOTELLA RODANICA	3.40	5.40	3.91	2.83	2.03	2.56	2.99	13.73	10.15	19.41	16.05	6.46	0.64
3	CYCLOTELLA OCELLATA	0.01					0.01							0.40
4	CYCLOTELLA STELLIGERA													
5	MELOSIRA CRENULATA	16.92	52.50	15.48	23.41	8.63	0.92	2.58	5.80	9.96	8.17	10.59	15.96	0.63
6	MELOSIRA GRANULATA	0.08			0.00			0.01						0.28
7	MELOSIRA VARIANS				0.01			0.04						0.01
8	MELOSIRA UNDULATA				0.05									
9	STEPHANODISCUS ASTREA	2.01	2.26	2.20	1.53	0.89	0.66	1.48	2.82	0.67	0.99	0.78	0.05	0.02
10	ACHNANTHES CLEVEI				0.01	0.00			0.03				0.00	0.01
11	ACHNANTHES EXIGUA	0.02			0.00	0.00					0.02			0.06
12	ACHNANTHES FLEXELLA		0.02	0.02		0.00	0.05	0.07	0.02		0.04	0.09		
13	ACHNANTHES LANCEOLATA	0.04	0.07	0.07	0.06	0.00	0.17	0.35	0.02	0.02			0.01	0.37
14	ACHNANTHES LINEARIS		0.02	0.02	0.00								0.21	0.04
15	ACHNANTHES MOLLII				0.00	0.00								0.04
16	ACHNANTHES PERAGALLI					0.01								
17	AMPHIPRORA PALUDOSA													
18	AMPHIPLEURA PELLUCIDA							0.04					0.05	
19	AMPHORA OVALIS	0.00	0.05		0.04	0.02	0.02	0.12					0.03	0.00
20	ASTERIONELLA FORMOSA	13.72	16.17	9.27	7.77	1.28	5.90	5.09	5.65	6.06	5.47	3.49	2.28	0.11
21	COCCONEIS DISCULUS					0.00	0.00	0.00						
22	COCCONEIS PLACENTULA	0.27	0.24	0.50	0.09	0.04	0.20	0.22	0.02	0.01	0.06		0.01	0.18
23	COCCONEIS RUGOSA	0.03	0.06		0.01	0.00	0.02							0.06
24	CYMBELLA CUSPIDATA					0.01		0.10			0.04			
25	CYMBELLA GRACILIS					0.00								0.01
26	CYMBELLA LANCEOLATA	0.03	0.07	0.02	0.01	0.01	0.05	0.02		0.01		0.00		
27	CYMBELLA VENTRICOSA	0.21	1.11	0.12	0.07	0.08	0.06	0.17	0.05	0.01	0.05	0.08	0.10	0.26
28	CYMBELLA SINUATA	0.04	0.08	0.04	0.03	0.01	0.01	0.03	0.02					0.01
29	CYMBELLA PROSTRATA		0.08						0.02					
30	CYMATOPLEURA SOLEA				0.01									
31	DIATOMA ANCEPS	0.01	0.02			0.01								0.00
32	DIATOMA HIEMALE		0.01			0.01		0.02						
33	DIATOMA VULGARE		0.02	0.03		0.00		0.37						
34	DIPLONEIS ELLIPTICA		0.02		0.01	0.00		0.01				0.02	0.00	0.01
35	DIPLONEIS OCULATA	0.01	0.03	0.03	0.03									
36	DIPLONEIS FINNICA													
37	EUNOTIA NAEGELII						0.02	0.04						
38	EUNOTIA TENELLA	0.02	0.04	0.01		0.00		0.07						0.00
39	EUNOTIA TRIODON	0.02												
40	EUNOTIA PERPUSILLA													
41	EUNOTIA PECTINALIS VENT.				0.01									
42	EUNOTIA PECTINALIS													
43	EPITHEMIA SOREX		0.03	0.01	0.04	0.02				0.02		0.03	0.01	0.08
44	EPITHEMIA TURGIDA		0.04		0.01	0.02	0.02	0.02	0.02	0.01			0.05	
45	EPITHEMIA ZEBRA	0.52	0.36	0.31	0.27	0.11	0.25	0.68	0.05	0.01		0.05	0.09	
46	EPITHEMIA ARGUS													0.05
47	FRAGILARIA CROTONENSIS	93.21	94.32	47.65	67.55	9.91	21.95	30.96	14.08	9.47	6.82	16.82	14.94	12.02
48	FRAGILARIA INTERMEDIA							0.03						
49	FRAGILARIA PINNATA	0.32	0.48	0.11		0.08	0.30	0.24					0.07	0.97
50	FRAGILARIA VAUCHERIAE		0.02						0.00					0.00
51	FRAGILARIA CONSTRUENS	0.49	0.04	0.01	0.14	0.01	0.06							0.65
52	FRAGILARIA LEPTOSTAURON													
53	FRAGILARIA CAPUCINA													0.06
54	FRUSTULIA RHOMBOIDES								0.00					
55	GOMPHONEMA ACUMINATUM		0.01				0.04	0.09						
56	GOMPHONEMA PARVULUM	0.03		0.07	0.03	0.01	0.07	0.15		0.01			0.00	0.05
57	GOMPHONEMA CAPITATUM			0.03	0.01									0.01
58	GOMPHONEMA VENTRICOSUM					0.01			0.00	0.02			0.01	0.05
59	HANTZSCHIA AMPHIOXYS				0.02									
60	GYROSIGMA ATTENUATUM													0.01
61	HANNEA ARCUS		0.03			0.01								
62	MASTOGLOIA SMITHII		0.02		0.01	0.02	0.04	0.03			0.03		0.01	0.01
63	MERIDION CIRCULARE				0.01	0.08	0.04	0.05	0.00				0.02	
64	NAVICULA AURORA	0.08	0.06	0.01	0.02	0.01	0.10	0.07	0.03			0.11	0.11	0.04

LAKE TAHOE 1970-1971*****PHYTOPLANKTON*****
****
AVERAGE NUMBER OF INDIVIDUALS PER ML

	DATE / SPEC.	2/ 4	15/ 4	2/ 5	13/ 5	16/ 6	24/ 8	2/ 9	20/ 1	3/ 2	12/ 2	24/ 2	23/ 4	5/10
65	NAVICULA BACILLUM	0.01	0.05		0.00	0.01	0.02	0.07	0.01	0.01			0.01	0.03
66	NAVICULA COCCONEIFORMIS	0.04	0.07	0.13	0.04	0.01	0.15	0.24	0.06	0.05		0.04	0.03	0.01
67	NAVICULA EXIGUA	0.01	0.05		0.02	0.00	0.05	0.09						0.24
68	NAVICULA FESTIVA							0.09						0.02
69	NAVICULA MUTICA	0.01		0.03		0.01		0.04	0.07					
70	NAVICULA PSEUDOSCUTIFORM.	0.04			0.04	0.09								
71	NAVICULA PUPULA	0.04	0.09	0.01	0.04	0.01	0.12	0.03					0.00	0.31
72	NAVICULA RADIOSA	0.11	0.11	0.04	0.02	0.01	0.24	0.20	0.01	0.00	0.01	0.08	0.03	0.58
73	NAVICULA SCUTELLOIDES		0.02											
74	NAVICULA CAPITATA			0.02										
75	NAVICULA CUSPIDATA													
76	NAVICULA COSTULATA													0.08
77	NEIDIUM HITCHCOCKII													
78	NEIDIUM AFFINE											0.00		
79	NITZSCHIA FILLIFORMIS	0.05	0.10	0.07	0.21	0.01	0.02	0.11	0.08	0.05			0.01	0.20
80	NITZSCHIA AMPHIBIA		0.01		0.32	0.00	0.12	0.57	0.90	0.91				0.37
81	NITZSCHIA SINUATA					0.00								
82	NITZSCHIA PALEA													0.29
83	OPEPHORA MARTYI					0.27								2.71
84	OPEPHORA AMERICANA	0.07												0.01
85	PINNULARIA BICEPS		0.02			0.01			0.00			0.01		
86	PINNULARIA AESTUARII		0.02			0.01								
87	PINNULARIA SUBCAPITATA													
88	PINNULARIA ABAUJENSIS													
89	PINNULARIA RUPESTRIS				0.02				0.01					
90	RHOICOSPHENIA CURVATA							0.04						
91	RHOPALODIA GIBBA	0.03		0.04	0.03	0.01	0.08	0.14	0.32	0.01	0.00	0.04	0.00	0.00
92	STAURONEIS PHOENICENTERON													
93	STAURONEIS SMITHII				0.01									
94	STAURONEIS ANCEPS								0.00					
95	SURIRELLA OVATA	0.09				0.01								
96	SYNEDRA AMPHICEPHALA													0.08
97	SYNEDRA MAZAMENSIS			0.02				0.01						
98	SYNEDRA RADIANS					13.02			46.10	99.60	115.45	190.37	23.43	8.63
99	SYNEDRA RUMPENS	0.02		0.04	0.02	0.01	0.02	0.01	0.04			0.03		
100	SYNEDRA SOCIA													
101	SYNEDRA ULNA		0.09	0.02	0.01	0.02			0.03			0.05	0.05	0.08
102	SYNEDRA INCISA						0.01							
103	TABELLARIA FENESTRATA								0.02					
104	TABELLARIA FLOCCULOSA					0.01								
105	TETRACYCLUS EMARGINATUS			0.03										
106	TETRACYCLUS LACUSTRIS			0.02		0.00								0.02
107	DIATOMELLA BALFOURIANA			0.02	0.03									
108	ACTINOCYCLUS EHRENBERGII					0.00							0.01	0.04
109	CALONEIS FENZLII													
110	CALONEIS SPECIOSA							0.02						
111	BIDDULPHIA AURITA													
112	GOMPHONEIS HERCULEANA					0.01		0.02					0.04	
113	ELAKATOTHRIX GELATINOSA								0.05	0.07		0.35		2.89
114	SCENEDESMUS QUADRICAUDA				0.01									
115	SPHAEROCYSTIS SCHROETERI	0.71	0.44	0.57	0.26	0.18	2.10	1.19	0.21	0.06	0.00	0.08	0.04	
116	STAURASTRUM PARADOXUM	0.04	0.19	0.04	0.02	0.03	0.12	0.02	0.04	0.05	0.07	0.05	0.01	0.03
117	BOTRYOCOCCUS BRAUNII													
118	OOCYSTIS NAEGELII													
119	PEDIASTRUM KAWRAISKYI													0.01
120	ULOTHRIX AEQUALIS												20.70	
121	ANABAENA SP.								3.08					
122	MERISMOPEDIA ELEGANS													
123	POLYCYSTIS AERUGINOSA				5.76									
124	DINOBRYON SERTULARIA	0.44	1.26	3.30	2.06		0.11	0.39	1.74	0.07	0.26	0.31	0.20	0.59
125	KEPHYRION OVUM											0.08		
126	MALLOMONAS													2.11
127	PERIDINIUM SP.	0.07	0.42	2.72	0.30	0.00	1.46	1.34	0.19	0.02	0.08	0.05	0.11	25.88
128	CERATIUM HIRUNDINELLA													
129	CRYPTOMONAS REFLEXA		0.02											1.61

APPENDIX D

LAKE TAHOE TOTAL PHYTOPLANKTON BIOMASS-DEPTH PROFILES

Freshweight biomass ($mg \cdot m^{-3}$) of the whole phytoplankton community vs. sampling depth at the index station of Lake Tahoe, 1967-1971.

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LAKE TAHOE 1967  ***PHYTOPLANKTON***

FRESH WEIGHT BIOMASS OF THE WHOLE PHYTOPLANKTON COMMUNITY

MILLIGRAM PER CUBIC METER

DEPTH  9/ 8     DEPTH 14/ 8     DEPTH 25/ 8     DEPTH  2/ 9     DEPTH  7/ 9     DEPTH 14/ 9     DEPTH 21/ 9     DEPTH 28/ 9
 (M)             (M)             (M)             (M)             (M)             (M)             (M)             (M)
  0.   24.08      0.    9.15      0.   13.39      0.   17.10      0.   17.09      0.   34.59      0.    5.95      0.    5.74
 12.   10.61      7.   20.95      7.   37.78      6.   19.86      4.   36.62      5.   34.73      5.   16.98      7.   19.56
 17.   40.18     12.   44.27     12.   37.28     13.   61.47      8.   32.27     11.   35.82     12.    9.92     15.   15.97
 28.   37.13     22.   31.51     22.   10.46     24.   42.88     17.   40.33     23.   55.62     24.   62.24     30.   56.35
 40.   30.29     60.   41.54     37.   46.40     38.  118.27     31.   62.96     38.   60.86     40.   71.66     50.  124.92
 50.   80.08    ************     50.  183.91     50.  177.51     43.   63.83     50.   64.55     52.  127.31     62.  127.49
 70.   66.62    ************    ************     70.  118.81     71.   60.47     72.   40.78     80.   80.99     89.   54.41


DEPTH  5/10     DEPTH 11/10     DEPTH 18/10     DEPTH 26/10     DEPTH  1/11     DEPTH  8/11     DEPTH 15/11     DEPTH  1/12
 (M)             (M)             (M)             (M)             (M)             (M)             (M)             (M)
  0.   20.47      0.   25.98      0.   24.38      0.   20.51      0.   26.58      0.   32.71      0.   31.61      0.   53.21
 10.   81.80     10.   26.61     10.   13.12     10.   14.81     10.   28.14     10.   35.53     10.   26.49     10.   77.04
 15.  155.36     15.   30.47     20.    9.14     15.   36.93     15.   16.46     15.   20.08     15.   23.69     15.   74.80
 20.  100.18     20.   37.02     40.   86.47     20.   38.50     20.   28.98     20.   30.74     20.   41.45     20.   43.77
 30.  115.07     30.   38.64     70.   80.55     30.   77.39     30.   42.46     30.   65.32     30.   66.53     30.   94.76
 50.  100.58     50.   55.16    ************     50.  116.57     50.  127.74     50.  120.14     50.   94.00     50.  104.76
 90.   81.19     90.   51.73    ************     90.  102.68     90.   54.81     90.   79.44     90.  105.55     90.  129.19
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LAKE TAHOE 1967-1968 ***PHYTOPLANKTON***

FRESH WEIGHT BIOMASS OF THE WHOLE PHYTOPLANKTON COMMUNITY

MILLIGRAM PER CUBIC METER

DEPTH (M)	8/12	2/ 1	16/ 1	24/ 1	8/ 2	14/ 2	20/ 2	28/ 2	6/ 3	13/ 3	20/ 3
0.	58.15	80.26	37.20	65.82	85.13	107.21	140.59	69.11	122.87	154.54	167.33
2.	******	******	******	******	******	******	******	******	******	******	******
5.	******	******	******	91.79	******	******	******	******	******	******	******
10.	49.48	89.41	53.78	92.41	106.14	119.01	112.81	99.94	165.51	130.02	164.99
15.	32.11	88.15	69.46	105.71	83.90	93.57	93.76	101.04	124.31	182.48	144.94
20.	63.98	85.36	70.23	91.36	86.07	101.52	137.97	112.55	122.83	156.79	153.44
30.	62.51	78.50	53.95	113.67	95.35	117.78	124.30	104.77	141.73	181.69	213.65
40.	******	******	******	89.66	******	******	******	******	******	******	******
50.	41.65	86.20	67.81	103.42	97.21	100.09	115.58	126.06	222.04	116.02	180.87
60.	******	******	******	******	******	******	******	******	******	******	******
75.	******	******	******	105.19	******	******	******	******	******	******	******
90.	30.68	86.90	87.44	83.98	117.07	148.20	96.39	174.13	151.15	207.70	160.87
105.	******	******	******	******	******	******	******	******	******	******	******
125.	******	******	******	******	******	******	******	******	******	******	******
150.	******	******	******	******	******	******	******	******	******	******	******

DEPTH (M)	28/ 3	2/ 4	11/ 4	18/ 4	25/ 4	1/ 5	9/ 5	16/ 5	22/ 5	29/ 5	5/ 6
0.	179.97	118.19	63.11	147.93	71.21	66.26	96.28	69.89	158.91	35.27	23.08
2.	******	******	******	******	******	******	******	******	******	60.29	25.40
5.	******	******	******	******	******	******	******	******	******	79.23	36.19
10.	163.77	134.50	73.54	141.90	101.07	66.25	110.32	105.64	148.98	40.95	46.02
15.	******	122.18	102.04	122.63	84.93	85.52	129.47	116.82	144.16	44.79	44.96
20.	162.35	183.14	92.67	176.45	119.27	97.52	153.65	89.06	154.35	21.31	40.76
30.	156.58	164.06	111.41	162.86	90.43	121.58	168.05	144.69	146.35	211.33	73.29
40.	******	******	******	******	******	******	******	******	******	******	62.71
50.	151.90	171.71	162.50	174.20	110.52	74.05	117.17	124.29	159.87	83.95	87.67
60.	******	******	******	******	******	******	******	******	******	78.76	84.34
75.	******	******	******	******	******	******	******	******	******	58.33	68.86
90.	175.13	152.41	177.94	219.52	187.97	195.82	193.77	163.10	216.36	74.38	48.74
105.	116.04	******	******	******	******	******	189.02	180.28	178.13	150.62	69.08
125.	******	******	******	******	******	******	******	******	******	******	******
150.	******	******	******	******	******	******	******	******	******	******	******

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LAKE TAHOE 1968  ***PHYTOPLANKTON***

FRESH WEIGHT BIOMASS OF THE WHOLE PHYTOPLANKTON COMMUNITY

MILLIGRAM PER CUBIC METER

DEPTH     12/ 6    19/ 6    26/ 6     4/ 7    11/ 7    17/ 7    24/ 7    31/ 7     7/ 8    12/ 8    21/ 8
 (M)
  0.      27.66    12.72    10.66     3.94     6.84     6.98    23.48    30.83    16.52    12.38    31.94
  2.     ******   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******
  5.      32.51    14.49    11.32    23.98    13.72    25.40    13.28    33.04    16.51    13.03    27.57
 10.      21.83     9.70    47.22    32.95     8.31    23.57    31.31    36.44    27.99    15.38    28.91
 15.      22.25     9.40     5.63    45.13    26.99    73.19   ******    11.88    27.12    26.07    40.35
 20.      39.29    14.33    16.40    38.75    21.56    49.50     0.00    24.36    29.91    24.07    30.59
 30.      52.62     8.55    30.92    51.39    30.51    70.32    33.69    45.69    37.89    28.84    51.45
 40.      59.56   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******
 50.      62.31    19.29    42.37    62.38    86.88    59.01    66.55    37.61    65.36    49.56    54.32
 60.      74.10   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******
 75.      75.26    24.23    26.91    66.31    43.58    64.46    63.95    51.97    49.13    54.05    76.75
 90.     104.59    55.84    42.49    56.27    56.89    49.69    42.58    70.23    67.06    55.89    79.81
105.      93.26   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******
125.     ******   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******
150.      89.11   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******


DEPTH     28/ 8     2/ 9    11/ 9    17/ 9    26/ 9    15/10    19/10    27/10     2/11     1/12     7/12
 (M)
  0.      88.16    25.99    30.81    15.16     9.63    24.33     7.93    25.02    27.45    31.12    38.82
  2.     ******   ******   ******   ******   ******   ******   ******   ******    19.30    43.35    37.89
  5.      73.35    46.54    32.72     7.65    11.29    18.12    28.12    19.42    20.22    61.00    40.28
 10.      81.93    26.70    41.99     3.40    17.44     7.16    25.92    11.86    16.98    88.81    42.93
 15.      39.65    43.86    49.34    19.83    50.36    43.76    37.45    18.51    14.77    55.19    31.06
 20.      87.88    54.53    55.40     8.84    23.75    39.22    27.07    47.54    23.33    83.84    32.61
 30.      85.52    37.26    61.90    29.60    62.06    15.39    51.26    88.51    26.64    50.50    41.14
 40.     ******   ******   ******   ******   ******   ******   ******   ******    56.54    58.30    30.89
 50.      52.28    54.99    67.93    22.97   105.64    75.10    64.84    96.39    64.71    53.15    63.40
 60.     ******   ******   ******   ******   ******   ******   ******   ******   114.60    76.00    86.50
 75.      68.52    53.26    76.10    26.14    47.65   100.94    99.84    85.65   101.73    95.23   109.65
 90.      75.06    42.14    61.61    86.54    75.66    71.11   110.19   145.40    64.88   136.85   132.20
105.     ******   ******   ******   ******   ******   ******   ******   ******    47.24    26.47    63.52
125.     ******   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******
150.     ******   ******   ******   ******   ******   ******   ******   ******   ******   ******   ******
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LAKE TAHOE 1968-1969 ***PHYTOPLANKTON***

FRESH WEIGHT BIOMASS OF THE WHOLE PHYTOPLANKTON COMMUNITY

MILLIGRAM PER CUBIC METER

DEPTH (M)	22/12	10/ 1	1/ 2	15/ 2	2/ 3	15/ 3	30/ 3	13/ 4	25/ 4	9/ 5	23/ 5
0.	53.97	60.01	35.62	78.26	52.90	127.85	87.66	159.47	167.20	93.25	54.74
2.	37.05	46.56	31.00	59.31	62.77	49.86	108.87	153.60	259.11	40.92	75.80
5.	59.76	42.01	39.71	49.44	51.76	60.85	79.95	151.29	132.73	82.61	11.57
10.	44.07	62.33	49.90	50.51	57.96	51.75	53.08	170.14	120.80	57.07	35.75
15.	32.13	54.96	41.19	59.29	68.44	66.27	90.99	156.11	229.96	155.73	35.22
20.	41.75	56.37	56.92	63.21	60.78	66.93	80.95	131.80	139.86	179.56	44.93
30.	31.37	58.70	64.54	50.70	70.12	37.06	90.01	128.20	223.76	168.87	76.25
40.	32.29	54.75	59.15	57.75	56.92	46.34	109.72	114.22	177.87	81.82	105.51
50.	54.61	47.85	44.06	41.68	55.72	77.35	109.19	73.89	184.95	166.69	83.00
60.	56.33	66.44	43.96	66.10	90.95	45.92	71.78	168.22	113.18	293.73	108.79
75.	30.52	76.01	75.54	69.08	76.20	86.38	113.82	101.37	110.74	198.30	110.34
90.	57.81	55.51	55.01	44.76	22.12	98.43	119.51	132.98	76.31	219.71	125.38
105.	56.28	55.38	59.24	41.59	50.30	20.92	78.25	110.69	173.90	163.32	122.26
125.	******	******	******	******	******	******	******	******	******	******	******
150.	******	******	******	******	******	******	******	******	******	******	******

DEPTH (M)	7/ 6	20/ 6	1/ 7	8/ 7	15/ 7	22/ 7	24/ 7	30/ 7	5/ 8	20/ 8	28/ 8
0.	20.93	11.89	12.18	12.94	18.42	420.08	9.14	27.06	12.68	13.34	54.77
2.	19.12	7.38	21.40	11.50	23.47	558.21	6.78	26.78	******	15.55	46.96
5.	37.84	21.24	18.63	23.26	41.01	13.45	******	14.59	20.40	10.11	49.58
10.	30.48	15.64	12.42	20.24	24.37	72.81	15.90	24.37	21.20	11.68	126.68
15.	61.00	26.27	15.66	25.24	54.15	54.72	******	37.34	17.24	8.49	58.44
20.	24.29	33.76	26.57	17.47	39.91	68.93	52.25	56.52	44.10	26.14	67.38
30.	115.94	97.94	47.30	45.47	82.89	38.91	48.73	8.24	42.56	15.35	40.58
40.	83.27	148.83	15.48	30.76	49.58	33.73	66.89	38.19	26.70	24.46	217.11
50.	257.66	181.16	25.58	35.67	34.98	98.28	72.51	80.58	53.17	41.15	123.44
60.	213.04	165.79	154.85	53.99	68.23	76.50	194.35	152.85	88.79	71.12	121.34
75.	157.83	160.50	119.45	89.02	4.02	376.63	******	114.47	123.84	60.35	273.28
90.	257.74	202.10	127.53	112.49	47.40	108.02	82.57	99.23	41.21	81.64	182.07
105.	138.80	185.91	128.98	119.48	85.25	89.51	40.48	83.02	89.69	110.66	125.09
125.	******	******	******	******	******	******	******	******	******	******	******
150.	******	******	******	******	******	******	******	******	******	******	******

LAKE TAHOE 1969-1970 ***PHYTOPLANKTON***

FRESH WEIGHT BIOMASS OF THE WHOLE PHYTOPLANKTON COMMUNITY

MILLIGRAM PER CUBIC METER

DEPTH (M)	3/ 9	9/ 9	15/ 9	24/ 9	10/10	22/10	28/10	12/11	23/11	5/12	16/12
0.	3.85	6.70	41.53	64.38	17.20	24.44	76.94	16.01	21.21	22.46	70.61
2.	5.63	5.34	84.58	10.47	37.30	9.62	20.21	48.75	27.98	27.28	68.54
5.	6.50	11.01	11.60	5.14	26.32	20.00	15.86	45.26	79.19	14.70	72.78
10.	9.81	15.25	43.56	4.73	26.28	11.95	16.52	18.88	32.54	27.57	65.69
15.	17.12	19.49	14.61	4.18	26.64	9.78	9.98	10.07	20.68	12.06	49.65
20.	19.41	32.21	104.58	26.26	20.08	72.46	79.48	16.12	35.27	16.61	34.20
30.	40.57	27.93	107.01	23.20	38.40	40.26	62.20	21.21	306.85	13.72	41.34
40.	33.73	31.76	86.37	45.64	******	50.69	55.30	13.26	35.50	24.74	51.61
50.	22.68	46.24	67.51	230.84	56.04	95.13	43.34	27.99	23.50	10.94	78.96
60.	41.37	56.97	74.60	282.16	******	85.66	124.25	46.43	27.94	43.07	56.33
75.	41.03	65.17	98.06	84.49	84.77	92.56	116.53	205.03	47.64	23.98	100.37
90.	40.84	75.86	******	66.20	86.77	111.52	132.50	61.06	36.63	30.15	83.15
105.	36.71	98.35	******	163.16	388.56	125.37	85.88	80.09	46.68	67.65	64.02
125.	******	******	******	******	******	******	******	******	******	******	******
150.	******	******	******	******	******	******	******	******	******	******	******

DEPTH (M)	26/12	6/ 1	19/ 1	30/ 1	10/ 2	23/ 2	28/ 2	16/ 3	23/ 3	2/ 4	15/ 4
0.	48.12	36.10	148.15	68.66	118.69	66.35	59.24	48.43	45.06	58.08	473.56
2.	39.67	28.09	163.04	64.40	317.51	79.88	43.52	66.25	69.18	59.17	117.42
5.	34.38	42.52	31.57	76.79	292.53	120.08	34.97	79.57	101.32	84.27	83.08
10.	82.69	43.76	85.76	89.76	199.42	75.84	84.06	163.73	46.02	85.94	438.95
15.	43.23	36.40	469.10	62.93	84.24	67.76	58.93	92.92	41.09	105.65	100.47
20.	61.82	36.81	540.51	56.21	294.79	112.11	59.38	63.32	43.56	111.61	218.86
30.	38.99	26.19	116.04	56.35	61.10	74.32	50.30	81.31	83.19	83.75	113.77
40.	33.59	41.84	235.06	41.18	266.37	37.70	67.33	66.70	94.01	60.08	249.66
50.	28.38	34.26	100.69	318.61	254.86	71.41	61.73	79.94	100.69	114.28	286.76
60.	48.42	32.55	916.16	342.82	175.76	76.09	55.70	138.46	67.43	69.89	296.53
75.	69.34	33.26	678.40	65.65	75.71	95.69	25.27	76.75	82.93	61.02	164.98
90.	59.27	43.54	766.04	45.23	61.39	80.55	62.61	63.62	80.99	70.36	124.29
105.	51.18	194.82	86.66	412.76	116.85	322.33	302.71	80.12	87.69	84.92	63.73
125.	******	******	******	******	******	******	******	******	******	224.82	92.41
150.	******	******	******	******	******	******	******	******	******	69.21	82.34

LAKE TAHOE 1970-1971 ***PHYTOPLANKTON***

FRESH WEIGHT BIOMASS OF THE WHOLE PHYTOPLANKTON COMMUNITY

MILLIGRAM PER CUBIC METER

DEPTH (M)	2/ 4	13/ 5	16/ 6	24/ 8	2/ 9	21/ 1	3/ 2	12/ 2	22/ 7	23/ 8	5/10
0.	34.73	72.34	33.89	4.82	8.14	152.47	402.01	334.19	470.71	309.64	31.79
2.	117.65	159.36	58.50	5.13	22.40	106.12	235.13	371.76	172.55	131.85	68.67
5.	81.01	87.82	17.97	13.59	20.36	171.80	231.23	303.21	464.67	67.47	42.52
10.	92.55	77.45	15.88	1.93	31.54	134.55	286.45	238.20	208.58	70.65	75.65
15.	77.71	56.54	14.66	6.52	46.01	203.80	239.02	294.77	350.86	56.49	68.76
20.	82.78	135.10	40.27	39.58	45.55	194.62	167.06	303.39	206.26	91.90	76.32
30.	165.53	91.95	22.54	49.34	49.67	169.39	200.83	207.78	267.22	449.49	126.31
40.	72.67	618.55	33.66	44.31	40.94	133.01	190.74	250.44	242.90	91.59	51.28
50.	98.67	60.23	55.12	35.23	41.80	189.50	244.57	208.67	178.60	88.13	46.16
60.	84.83	217.52	45.57	46.29	53.83	124.40	394.19	266.38	236.94	138.45	86.79
75.	74.55	124.67	40.91	31.77	64.89	215.76	232.77	205.78	242.14	116.74	50.23
90.	87.00	80.81	38.38	61.22	104.20	119.69	262.36	302.92	221.25	41.08	88.78
105.	143.43	49.94	71.07	54.61	66.60	146.90	135.90	250.12	374.60	41.86	83.28
120.	96.62	96.85	67.82	******	******	******	******	******	******	******	******
150.	******	******	92.43	******	******	******	******	******	******	******	******

APPENDIX E

LAKE TAHOE WATER CHEMISTRY METHODS

NITRATE ANALYSES

Nitrate-nitrogen concentrations are determined by the method described by Strickland and Parsons (1968). In this procedure, the nitrate ion is reduced to nitrite ion by finely-divided particles of cadmium-copper amalgam under mildly acidic conditions. A diazotization reaction between nitrite (nitrous acid) and sulfanilamide followed by a coupling reaction with N-(1-naphthyl)-ethylenediamine produces a red azo dye whose absorbance is measured at 543 nm. The results of analyses are expressed in terms of parts per billion of nitrate-nitrogen (i.e., micrograms of elemental nitrogen present in the nitrate form per liter of solution).

Reagents

Concentrated Ammonium Chloride Solution -
Weigh 175.0 ± 0.1 g analytical reagent grade ammonium chloride (NH_4Cl) and dissolve in 500 ml of freshly deionized and distilled water. Store in a clean, tightly-stoppered glass or polyethylene bottle.

Dilute Ammonium Chloride Solution -
Dilute 50.0 ml of the concentrated NH_4Cl solution to 2000 ml with deionized and distilled water. Store in a glass or polyethylene bottle.

Sulfanilamide Hydrochloride Solution -

In a 500 ml volumetric flask, prepare a solution of 50.0 ± 0.5 ml analytical reagent grade concentrated (12 M) hydrochloric acid dissolved in approximately 300 ml of deionized and distilled water. Weigh 5.00 ± 0.05 g sulfanilamide and dissolve it in the above dilute HCl solution. Dilute the mixture to exactly 500 ml with deionized and distilled water. When stored in a tightly-stoppered glass or polyethylene bottle at room temperature this solution remains stable indefinitely.

Concentrated Synthetic Seawater Medium -

Dissolve 620 ± 1 g analytical reagent grade sodium chloride (NaCl), 200 ± 1 g analytical reagent grade magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$), and 1.00 ± 0.01 g analytical reagent grade sodium bicarbonate ($NaHCO_3$) in 2000 ml of deionized and distilled water. Store in a glass or polyethylene bottle.

Amalgamated Cadmium-Copper Filings -

Remove metal filings from analytical reagent grade cadmium sticks with a coarse hand file. With a sieve, separate and discard the fraction that passes through 0.5 mm openings. Stir approximately 90 g of cadmium filings (enough for two reductor columns) with 400-500 ml of 2% copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) solution until all blue color has disappeared and a suspension of metallic copper particles has formed in the solution. At this point, decant and discard the suspension of fine particles. Rinse the copper-coated Cd filings with several portions of the dilute NH_4Cl solution to remove the fine particles which, if not removed now, may restrict the flow of water samples through the reduction columns. Push a small plug of glass wool, or copper wool if available, into the bottom of the reduction column. Partially fill the column with dilute NH_4Cl solution and slowly pour in the slurry of Cu-Cd filings while tapping the column to encourage uniform packing of the filings as they settle. When the filings reach a height of 30 cm, insert another small plug of copper wool or glass wool to cover the filings, and wash the column thoroughly with two or three 100-ml aliquots of dilute NH_4Cl solution. Store the column filled with this solution to prevent the filings from drying out. Wrap the column with opaque tape or foil to prevent the exposure of the filings to light.

Properly prepared and handled columns will typically retain their effective reducing ability for at least six months, even if weekly batches of 20 samples or more per column are analyzed. With time, however, columns become physically obstructed and Cu-Cd filings become coated with unreactive oxide or carbonate films causing a decrease in the overall sensitivity of the method. When this occurs, the filings should be emptied from the column and the filings should be washed by stirring vigorously with approximately 150 ml of 0.5 M HCl solution. Decant the suspended particulate material and repeat the treatment with the HCl two more times. Wash the clean filings thoroughly to remove the excess acid and decant as much water as possible. Since some Cd dissolves during this treatment, it is necessary to add additional fresh Cd filings to replace it. Retreat the metal filings with $CuSO_4$ solution as described above.

N-(1-Naphthyl)-Ethylenediamine Dihydrochloride Solution -
Weigh 0.500 ± 0.005 g $C_{10}H_7NHCH_2CH_2NH_2 \cdot 2HCl$ (Eastman Organic Chemicals #4835) and dissolve in 500 ml deionized and distilled water. Store in a dark glass bottle completely wrapped with foil or opaque tape and refrigerate during storage. Check the color of this solution prior to use and discard monthly or more frequently if a yellow-brown coloration develops.

Standard Nitrate Solution (100 ppm nitrate-nitrogen) -
Oven-dry a sample of primary standard grade or analytical reagent grade potassium nitrate (KNO_3) to constant weight at 110 - 120°C. Weigh

0.7218 ± 0.0002 g KNO_3 after cooling in a desiccator to room temperature. Transfer the sample to a 1000-ml volumetric flask, dilute to the mark with deionized and distilled water, and mix thoroughly. Store in a tightly-sealed glass bottle. As needed, standard solutions of lower nitrate-nitrogen concentration are prepared by quantitative dilution of this 100 ppm standard. For example, a 50 ppb nitrate-nitrogen standard solution may be prepared by diluting 1.00 ± 0.01 ml (Class A volumetric pipette) of the 100 ppm standard nitrate solution to 2000 ml with deionized and distilled water in a volumetric flask.

Procedure

1. Add 2.00 ± 0.05 ml concentrated ammonium chloride solution and 10.0 ± 0.1 ml concentrated synthetic seawater medium to each 90.0 ± 0.5 ml sample in 125-ml Erlenmeyer flasks equipped with rubber snap-caps. The ammonium chloride and synthetic seawater solutions are most conveniently introduced via automatic pipettes capable of the stated precision, while 100-ml polypropylene graduated cylinders (which drain completely and cause negligible meniscus error due to the hydrophobic nature of this plastic) allow adequate precision for measuring sample volumes.

2. Prior to the introduction of the first sample, the cadmium-copper reduction columns must be drained of the dilute ammonium chloride solution contained in them and flushed with an additional 100-150 ml of fresh dilute ammonium chloride solution. While rinsing the columns, the flow rates should be equalized by adjusting the Teflon needle valve at the base of each column. A flow rate of approximately 8 minutes per 100 ml is typical. Once established, the flow rates must remain constant for all samples and standard solutions to ensure the same reduction efficiency. Allow the rinse solution to drain to within 2-3 cm of the top of the bed of Cd-Cu filings and prepare

to pour the standard and sample solutions through the reducing columns. Because of the potential danger of contaminating one sample with the residue of the previous sample that has been passed through the column, it is desirable to analyze samples of similar origin and/or concentration in consecutive order.

3. Begin rinsing the column with approximately 5 ml of one of the sample solutions and allow it to pass through the column. Such rinsings should be collected in a flask or beaker and will be discarded. Repeat this rinsing process four or five more times with 5-ml aliquots. The series of small successive rinses decreases the probability of contaminating the remainder of the sample with the previous one. Continue to rinse, adding all but approximately 55 ml of the solution. When this last rinse has entered the bed of Cd-Cu filings, add the remaining 55 ml of sample and begin collecting the effluent in a 50- or 100-ml polypropylene graduated cylinder containing 1.00 ml of the sulfanilamide solution. (The presence of the sulfanilamide at this point ensures improved reproducibility between trials while also enhancing the sensitivity of the method by utilizing a greater proportion of the unstable nitrous acid for the formation of the diazonium intermediate).

4. Collect a total of 50.0 ± 0.5 ml of effluent (51.0 ml total including the 1.00 ml of sulfanilamide solution originally pipetted into the graduated cylinder), mix the solution, and transfer this back into the original drained 125-ml Erlenmeyer flask where the diazotization reaction is permitted to continue for exactly 5 more minutes.

5. Add 1.00 ± 0.01 ml of N-(1-naphthyl)-ethylenediamine dihydrochloride solution and mix well. Allow at least 20 minutes for color development. Avoid excessive warming of the samples or illumination by bright artificial light or sunlight as these factors are responsible

for irregular color development and premature fading of the azo dye.

6. Measure the absorbances of the samples at 543 nm between 20 minutes and 2 hours after color development. Selection of cell pathlength (1 cm, 4 cm, or 10 cm) will depend upon the nitrate concentrations being measured. As a general rule, the longest pathlength cells which give sample absorbance values less than about 0.6 - 0.8 should be used. Because the absorbance scales of most spectrophotometers are compressed for high readings (i.e., absorbances greater than about 0.4), more accurate measurements may be obtained by recording the linear % transmittance values and converting later to absorbance (sometimes called "optical density") by the use of a conversion table such as the "Transparency to Optical Density Conversion Table" (Chemical Rubber Co. 1971).

7. The reliability of the results from this method are dependent upon a consistent reduction efficiency of each Cd-Cu column. To monitor this important factor, a series of standards should be analyzed before and after every 10-15 samples. In addition, occasional replication (duplicate or triplicate) of samples is essential to provide an estimate of overall precision of the method. A minimum of three different concentrations of standard solutions should be used. The most concentrated standard solution should have more ppb nitrate-nitrogen than the most concentrated water sample to eliminate the necessity of extrapolating the standard curve.

8. Prepare a standard curve of corrected absorbances versus ppb nitrate-nitrogen, where $A_{corr} = A_{standard} - A_{blank}$.

9. The absorbance readings of the samples are corrected for the nitrate contamination of the deionized and distilled water in which the

reagents are dissolved by the following equation:

$$A_{corr} = A_{sample} - (12/102)A_{blank}$$

The concentrations of nitrate-nitrogen corresponding to these corrected sample absorbances are then read from the corrected standard curve prepared in the previous step. A discussion of the significance of these formulae is presented in the following section.

Blank Corrections for Nitrate Analyses

Non-zero absorbance values for reagent blanks, representing an apparent contamination by the analytical reagent grade chemicals and/or the deionized and distilled water, are encountered in every type of analysis involving a high level of sensitivity. Blank corrections are especially critical for nitrate analyses of Lake Tahoe water since many of these samples have nitrate-nitrogen concentrations below 5 ppb and occasionally lake water samples exhibit uncorrected absorbances less than the blanks themselves. Our experiences at Lake Tahoe indicate that these results are explicable only if one assumes that the solid analytical reagent grade chemicals contribute negligible amounts of nitrate-nitrogen and that the deionized and distilled water are fully responsible for the contamination. The blanks, standards, and lake water samples all contain exactly the same quantities of reagent grade chemicals, but different amounts of deionized and distilled water (102 ml for the blanks and standards, and only 12 ml for the lake water samples).

Since all of the standard samples and blanks contain the same reagents and about 102 ml of deionized and distilled water (90 ml sample + 10 ml synthetic seawater + 2 ml concentrated NH_4Cl solution), the full value of A_{blank} is subtracted from each standard ($A_{corr} = A_{standard} - A_{blank}$). Since the 12 ml of reagent solutions added to each lake water sample (synthetic seawater and ammonium chloride solutions) were prepared with deionized and distilled water containing nitrate contamination, the true nitrate content of the samples may be obtained by eliminating the effect of the slightly contaminated deionized and distilled water by subtracting (12/102) A_{blank} from each sample absorbance ($A_{corr} = A_{sample} - (12/102)\ A_{blank}$). These corrected absorbances are then used to find the true sample concentrations from the corrected standard curve. It should be apparent that the factor (12/102) is used because only 12 ml of the total sample (90 ml lake water + 12 ml reagents) contribute water containing nitrate contamination. On the other hand, nitrate standards contain 102 ml of nitrate contaminated water so the full value of A_{blank} is subtracted from $A_{standard}$.

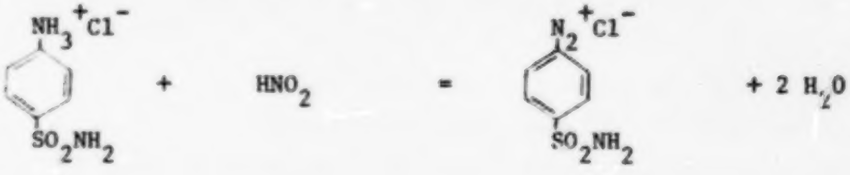
Chemistry

Reduction of NO_3^- by Cd-Cu Column -

$$\begin{array}{r} 3\ H^+ + NO_3^- + 2\ e^- = HNO_2 + H_2O \\ Cd = Cd^{++} + 2\ e^- \\ \hline 3\ H^+ + NO_3^- + Cd = HNO_2 + Cd^{++} + H_2O \end{array}$$

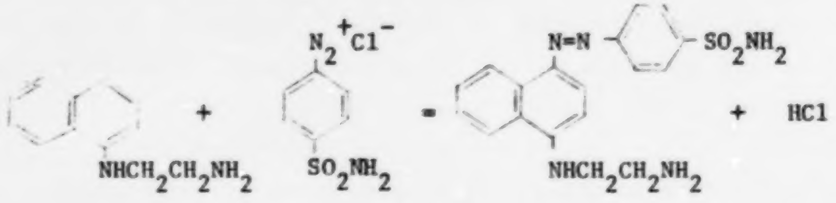
(I)

Diazotization Reaction -



(II) (I) (III)

Coupling Reaction (Dye Formation) -



(IV) (III) (V)

(I) = nitrous acid
(II) = sulfanilamide hydrochloride
(III) = p-benzenesulfonamide diazonium chloride
(IV) = N-(1-naphthyl)-ethylenediamine
(V) = an azo dye

PHOSPHATE ANALYSES

Described here are three related methods for the analysis of dissolved and particulate forms of phosphorus in natural waters. Depending upon the type of preliminary sample treatment, the concentrations of different forms of phosphorus may be determined:

1. Total phosphorus (including both dissolved and particulate fractions) by acid hydrolysis of unfiltered samples.

2. Total dissolved phosphorus (including both inorganic and organic compounds) by the analysis of acid-hydrolyzed, filtered samples.

3. Soluble orthophosphate by the analysis of filtered samples without the acid hydrolysis steps.

Acid hydrolysis at 115-120°C releases a large proportion of the phosphorus present by converting it into soluble orthophosphate from particulate inorganic phosphate minerals, from dissolved and particulate phosphorus compounds, and from soluble condensed inorganic forms such as pyrophosphates, metaphosphates, and tripolyphosphates. The following hydrolysis procedure is used:

1. Add 1.00 ml of 10.8 N H_2SO_4 per 100 ml of water sample.

2. Autoclave the samples at 115-120°C for 15 minutes (total heating time is approximately one hour including depressurization and cooling cycles). If an autoclave is not available, heat the samples in a pressure cooker at the boiling point for one hour.

3. Add 3-5 drops of phenolphthalein indicator solution to each sample and carefully neutralize by adding about 1.00 ml of 10.8 N NaOH per 100 ml of water sample.

4. Continue with the procedure given below.

The following method is based on the reduction of a phosphomolybdate complex by ascorbic acid and is similar to the methods described in Murphy and Riley (1962) and Strickland and Parsons (1968). An intensely-colored blue sol ("molybdenum blue") is produced whose absorbance at 675 nm varies directly with the orthophosphate content of the sample.

Reagents

Unless otherwise specified, all chemicals should be analytic reagent grade. All reagent bottles, filters, and glassware should be thoroughly acid-leached with a dilute HCl solution prepared from about 10-20 ml of concentrated HCl in 1000 ml of deionized and distilled water; detergents should never be used to clean glassware used for phosphate analyses.

Molybdenum-Antimony Reagent -

Introduce approximately 1500 ml of deionized and distilled water to a 2000-ml graduated cylinder set aside for this sole purpose. Slowly and cautiously add 244 ml of concentrated H_2SO_4 while mixing well with a magnetic stirrer. Allow the solution to cool for approximately one hour and then add 21.00 ± 0.01 g ammonium heptamolybdate tetrahydrate, $(NH_4)_6\ Mo_7O_{24} \cdot 4H_2O$ and 0.600 ± 0.001 g antimony potassium tartrate, $K(SbO)C_4H_4O_6 \cdot 1/2H_2O$. Continue to mix until the solids have dissolved in the sulfuric acid solution and when it has cooled to room temperature dilute to the 2000-ml mark with deionized and distilled water. Mix thoroughly and store the solution in a tightly-stoppered glass or polyethylene bottle.

Ascorbic Acid Solution -

Dissolve 3.00 + 0.01 g of ascorbic acid in 100 ml of 95% ethanol; store in the refrigerator. This solution is stable for at least one month. An alternative is to dissolve the ascorbic acid in 100 ml of deionized and distilled water. However, this aqueous solution must be prepared fresh daily.

10.8 N H_2SO_4 Solution -

Add 300 ml of reagent grade concentrated H_2SO_4(36 N) to about 500 ml distilled water in a 1000-ml volumetric flask. Mix well and allow to cool to room temperature. Dilute to the 1000-ml mark with distilled water and mix again.

10.8 N NaOH Solution -

Weigh 432 ± 1 g of analytical reagent grade NaOH and transfer the pellets to a 1000-ml volumetric flask and add approximately 300 ml deionized and distilled water. Mix cautiously by swirling the unstoppered flask to dissolve the NaOH and then stopper the flask and cool the solution to room temperature. Dilute to the 1000-ml mark and mix well. Store the solution in a tightly-stoppered polyethylene bottle.

Butyl Acetate -

"Purified" grade (J. T. Baker Chemical Co. or equivalent).

Standard Phosphate Solution (100 ppm phosphate-phosphorus) -

Oven-dry a sample of analytical reagent grade potassium dihydrogen orthophosphate (KH_2PO_4) to constant weight at 105-110°C. Weigh 0.4393 ± 0.0002 g KH_2PO_4 and dissolve in a 1000-ml volumetric flask with deionized and distilled water. Mix the solution thoroughly and store in a tightly-stoppered glass bottle after adding a few drops of chloroform as a preservative.

Phenolphthalein Indicator Solution -

Dissolve 0.10 g of phenolphthalein powder in 50 ml of 95% ethanol and add 50 ml of deionized and distilled water.

Procedure for the Determination of High Levels of Phosphate

If the concentration of orthophosphate is greater than about 50 ppb PO_4-P, the absorbance of the blue phosphomolybdate complex may be obtained by measuring the unextracted aqueous solution in 4-cm pathlength cells at 675 nm. Below this concentration, increased sensitivity may be gained by doubling the size of the sample and by extracting the blue complex from the aqueous phase and concentrating it in a small volume of butyl acetate (described in the next section).

1. To 100.0 ± 0.1 ml of water sample in a 125-ml Erlenmeyer flask add 10.0 ± 0.1 ml of the molybdenum-antimony reagent and 1.00 ± 0.01 ml of ascorbic acid solution and mix well after the addition of each reagent.

2. Wait a minimum of 30 minutes for the blue color to develop.

3. Measure the absorbances of the samples at 675 nm in 1-cm or 4-cm pathlength cells. Cell pathlength should be selected so that the majority of the sample absorbance values fall in the range from about 0.2 - 0.6.

4. Duplicate standards having at least three different phosphate concentrations and spanning the full range of phosphate concentrations anticipated in the samples should be prepared with each day's determinations. Duplicate blank samples consisting of 100 ml deionized and distilled water each must also be analyzed.

5. Prepare a standard curve of corrected absorbances plotted against ppb phosphate-phosphorus, where $A_{corr} = A_{standard} - A_{blank}$.

6. The absorbance readings of the samples are corrected for phosphate contamination in the color development solutions added by the following formula:

   $$A_{corr} = A_{sample} - (11/111)A_{blank}$$

   The corrected absorbance is then read from the corrected standard curve to obtain the concentration of phosphate-phosphorus in the sample. The conversion factor (11/111) is used because only 11 ml of the total sample (100 ml water sample + 11 ml reagents) contribute deionized and distilled water with possible traces of orthophosphate, while the blanks and standards contain 111 ml of the slightly contaminated deionized and distilled water. With care, phosphate blanks having absorbances of 0.000-0.005 in 4-cm pathlength cells can be obtained routinely.

Procedure for the Determination of Low Levels of Phosphate

For orthophosphate concentrations below approximately 50 ppb phosphate-phosphorus, the sensitivity may be enhanced by increasing sample sizes to 200 ml (or more) and by extracting the blue complex into 10 ml of butyl acetate. If absorbances greater than 1.0 are obtained even in 1-cm pathlength cells, sample sizes may be decreased to 100 ml or 50 ml while maintaining the same volume of butyl acetate. Solvent extraction using butyl acetate is also an effective method of separating the blue phosphomolybdate complex from samples which exhibit high levels of turbidity.

1. To 200 ± 2 ml of the water sample (measured with an acid-rinsed graduated cylinder or a modified, rapid-draining pipette) in a separatory funnel, add 20.0 ± 0.1 ml of molybdenum-antimony solution and 2.00 ± 0.02 ml of ascorbic acid solution. Mix thoroughly after adding each reagent and allow 30 minutes for color development.

2. Carefully add 10.0 ± 0.1 ml of butyl acetate to the separatory funnel using an automatic pipette. Stopper the separatory funnel tightly and shake vigorously for exactly 3.0 minutes. It is convenient to extract two or more samples simultaneously. Extraction efficiency is a function of the extent to which the aqueous and organic phases mix together. Therefore, extraction time as well as shaking frequency and vigor must be identical for all samples.

3. Allow the aqueous and organic phases to separate. Drain off and discard the lower aqueous phase. Collect the remaining butyl acetate solution in a 15-ml centrifuge cone. Centrifuge the sample for approximately 5 minutes to separate inadvertently-transferred water droplets that may contribute to turbidity in the butyl acetate phase.

4. Transfer the butyl acetate solution into a 1-cm pathlength cell (or larger) and measure the absorbance at 675 nm against pure butyl acetate in the reference cell.

5. A minimum of three different phosphate standard solutions in duplicate should be prepared with each day's determinations. They should span the full range of phosphate concentrations found in the samples analyzed. Two blank samples consisting of 200 ml distilled water each must also be analyzed.

6. Prepare a standard curve of corrected absorbance vs. ppb elemental P, where $A_{corr} = A_{standard} - A_{blank}$.

7. The absorbance readings of the samples are corrected for phosphate contamination in the color development solutions added by the following formula:

$$A_{corr} = A_{sample} - (22/222)A_{blank}$$

The concentration of phosphate-phosphorus in the sample corresponding to the corrected absorbance is then read from the corrected standard curve. The factor (22/222) appears in the formula because only 22 ml of the total sample (200 ml water sample and 22 ml reagents) are contributed by deionized and distilled water containing possible traces of phosphate ion.

TOTAL IRON ANALYSES

The determinations of iron are complicated by the many varied forms in which iron exists in water samples: colloidal and complexed ferric iron, insoluble iron minerals (sand, clay, etc.), soluble ferrous iron released under anaerobic conditions, soluble and particulate organic iron compounds, and insoluble ferric hydroxide. The procedure described here provides a measure of the "biologically reactive iron" that is released by a preliminary treatment with hydrochloric acid. This treatment is believed to release iron from each of the previously-mentioned sources that is likely to be available to phytoplankton. The measurement of the true total iron content of the sample would require a much more vigorous acid digestion process involving complete dissolution of all of the above sources by $HClO_4$ and HF.

Reagents

Bathophenanthroline Solution -

Dissolve 0.175 ± 0.001 g of analytical reagent grade bathophenanthroline (4,7-diphenyl-1, 10-phenanthroline) in 250 ml ethanol. Then add 250 ml distilled water and store in a tightly-stoppered polyethylene bottle that has been thoroughly acid-washed. Although the solution is stable indefinitely, great care must be taken to prevent contamination by dust, residue on pipettes, etc. that may contain traces of iron.

Hydroxylamine Hydrochloride Solution -

Even analytical reagent grade $NH_2OH{\cdot}HCl$ contains appreciable amounts of iron which will cause high blank values in this procedure. Dissolve 20.0 ± 0.1 g of analytical reagent grade $NH_2OH{\cdot}HCl$ in 200 ml of deionized and distilled water in an acid-leached separatory funnel (store funnels filled with dilute HCl). Add about 5 ml of the bathophenthroline solution and mix. Then add 10 ml isoamyl alcohol and shake vigorously for 1 minute to extract as much of the red-orange iron complex as possible. Extract 2 more times with additional 10 ml aliquots of isoamyl alcohol until the extracts are colorless. Add 5 ml of bathophenanthroline and repeat the extraction steps. Allow the final extraction mixture to separate at least 10 minutes before draining the lower aqueous $NH_2OH{\cdot}HCl$ solution into a clean polyethylene bottle. Store in the refrigerator.

5 N Hydrochloric Acid Solution -

Dilute 210 ± 5 ml of analytical reagent grade concentrated HCl (specific gravity = 1.19; concentration = 12 N) to 500 ml with deionized and distilled water in an acid-washed volumetric flask. Store the solution in a clean polyethylene bottle.

Sodium Acetate Buffer Solution -

In a 2000-ml graduated cylinder (acid-washed), add 320 ± 2 ml glacial acetic acid to about 500 ml deionized and distilled water. Add 1088 g reagent grade sodium acetate trihydrate and add deionized and distilled water to the 2000-ml mark. Store the solution in a clean polyethylene bottle.

Isoamyl Alcohol -

Also called "isopentyl alcohol" or "3-methyl-1-butanol". Use analytical reagent grade.

Standard Iron Solution (200 ppm Fe) -

Weigh out 1.4043 g analytical reagent grade ferrous ammonium sulfate hexahydrate, $FeSO_4(NH_4)_2SO_4 \cdot 6H_2O$. In a clean 1000-ml volumetric flask, dissolve the salt in about 100 ml distilled water and 20 ml concentrated reagent grade HCl. Add distilled water to the 1000-ml mark and mix well. Store in a clean, tightly-stoppered container.

Procedure

This procedure is applicable to the determination of up to 30-40 micrograms of Fe.

1. Mix the samples to resuspend solid material uniformly. With a clean pipette (the tip of the pipette should be shortened approximately 2-3 mm to allow particulate material to pass through the enlarged opening

and promote rapid draining), measure an appropriate aliquot of the samples into acid-washed Erlenmeyer flasks or reagent bottles. Rinse the pipette with deionized and distilled water allowing the rinsings to drain into the flask. Use the following table as a guide for the selection of sample sizes:

ppb Fe	Sample Volume	Separatory Funnel Volume	Cell Size
0 - 150	100 ml	200 - 250 ml	4 cm
150 - 500	50 ml	125 ml	1 cm
500 - 1000	25 ml	125 ml	1 cm
1000 - 4000	10 ml	125 ml	1 cm

2. Add 1.0 ± 0.1 ml of 5 N HCl and 3.0 ± 0.1 ml $NH_2OH \cdot HCl$ solution to each sample. Mix well and cover with a loosely-fitting glass stopper or a rubber snap-cap.

3. Autoclave the samples at 115-120°C for 15 minutes (total heating time is approximately one hour including depressurization and cooling cycles). If an autoclave is not available, heat the samples in a pressure cooker at the boiling point for one hour.

4. Cool the samples to room temperature. Add 5.0 ± 0.1 ml sodium acetate buffer solution to each sample with an automatic pipette and mix well.

5. Then add 3.0 ± 0.1 ml bathophenanthroline solution, mix, and allow the color to develop for 10 minutes.

6. Transfer the sample quantitatively to a separatory funnel. Add rinses with deionized and distilled water to the separatory funnel.

7. Add 10.0 ml of isoamyl alcohol by automatic pipette to the separatory

funnel. Shake each funnel vigorously for exactly 2.0 minutes. It is often most convenient to extract two or more samples simultaneously. Extraction efficiency is a function of the extent to which the aqueous and organic phases mix together. Therefore, extraction time as well as shaking frequency and vigor must be identical for all samples.

8. Allow the layers to separate and discard most of the lower aqueous layer. Swirl the funnel to dislodge additional water droplets and allow the phases to separate. Discard the lower aqueous layer and the first milliliter of the alcohol layer. Collect the remainder of the alcohol fraction in a 12-20 ml centrifuge cone. Due to traces of water, the alcohol extract is often turbid. The cones should be centrifuged for about 5 minutes or until transparent before making absorbance measurements.

9. Within one hour of extraction, measure the absorbance at 533 nm using isoamyl alcohol as the reference. Sample volumes and spectrophotometer cells should be selected to obtain absorbance readings in the range from about 0.2 to 0.6.

10. Standard iron solutions with at least 3 different Fe concentrations spanning the range of Fe concentrations expected in the samples and a blank are required. All must be autoclaved along with the samples to assure complete reduction of Fe^{3+} to Fe^{2+} by the hydroxlamine. Using aliquots identical in size to those of the samples and following Steps 1 - 9 in the above procedure, prepare extracts from each of the three standard solutions and one distilled water blank.

11. Prepare a standard curve of uncorrected absorbances versus ppb Fe.

12. Determine the iron concentration in each sample by finding the ppb Fe

corresponding to the uncorrected sample absorbances. In our analyses there is much evidence to support the idea that the reagents and not the deionized and distilled water are fully responsible for the iron contamination observed in the blank samples. The above data treatment is therefore analogous to the more tedious process of subtracting the blank absorbance from all of the standard absorbances, constructing a standard curve of corrected absorbances versus ppb Fe, subtracting the blank absorbance from all of the sample absorbances, and finding the ppb Fe in each sample by comparing corrected absorbances to the corrected standard curve.

AMMONIA (LOW LEVEL) ANALYSES

Ammonia concentrations are determined by a modified method utilizing the blue indophenol reaction between ammonia, phenol, and hypochlorite at high pH as reported by Solorzano (1969). Although the reaction has been known since 1859 (Berthelot), it could not be applied to the determination of ammonia in natural waters containing high concentrations of Ca^{2+} or Mg^{2+}. In this new procedure, calcium and magnesium interference is eliminated by complexing with sodium citrate. Other advantages of this method are the elimination of distillation or solvent extraction steps, improved sensitivity over nesslerization methods, speed, stability of blue coloration, and absence of reaction with other forms of nitrogen. It is reported that glycine, alanine, lysine, histidine, arginine, tyrosine, glutamic acid, urea, and nucleic acids do not interfere. The method is applicable in the range of ammonia concentrations from 0 to 500 ppb NH_3-N with negligible departure from the Beer-Lambaert law. The limit of detection is approximately 5 ppb NH_3-N.

Reagents

Unless otherwise specified, all chemicals should be analytic reagent grade.

Phenol-Ethanol Solution -

Dissolve 50.0 ± 0.1 g of analytical reagent grade phenol in 500 ml 95% ethanol. Avoid chemical burns from phenol!

Sodium Nitroferricyanide, 0.5% Solution -

Dissolve 2.50 ± 0.01 g of analytical reagent grade sodium nitroferricyanide (also called sodium nitroprusside) in 500 ml freshly deionized water. Store in a dark bottle wrapped with aluminum foil in the refrigerator; replace monthly.

Alkaline Citrate Solution -

Dissolve 200.0 ± 0.1 g analytical reagent grade trisodium citrate dihydrate and 10.00 ± 0.05 g analytical reagent grade sodium hydroxide in 1000 ml of freshly deionized water.

Sodium Hypochlorite Solution (NaOCl) -

Use analytical reagent grade sodium hypochlorite solution. In an emergency, commercial bleach such as Chlorox may be used if it is fresh. Store this reagent in a dark bottle in the refrigerator.

Oxidizing Solution -

Mix 100 ml of sodium citrate-sodium hydroxide solution with 25 ml of sodium hypochlorite solution (or other appropriate volumes in a 4:1 ratio). Prepare this mixture fresh daily.

Standard Ammonia Solution (50 ppm NH_3-N) -

The standard solution may be prepared from either oven-dried (110°C), analytical reagent grade ammonium chloride or ammonium sulfate. Weigh 0.3818 ± 0.0002 g NH_4Cl or 0.4617 ± 0.0002 g $(NH_4)_2SO_4$, transfer to a 2000-ml volumetric flask, and dilute to 2000 ml with freshly-deionized, non-distilled water. Store in a clean tightly-stoppered bottle.

Procedure

1. Measure 50.0 ± 0.5 ml of sample into a clean 125-ml Erlenmeyer flask with a graduated cylinder or a modified, rapidly-draining volumetric pipette.

2. Add 2.0 ± 0.1 ml of the phenol-ethanol solution and mix.

3. Add 2.0 ± 0.1 ml of the sodium nitroferricyanide solution and mix.

4. Add 5.0 ± 0.1 ml of the oxidizing solution. Mix thoroughly and allow the blue color to develop for a minimum of two hours.

5. Measure the absorbances at 640 nm in 4-cm pathlength cells if the solutions are yellow or yellow-green (ammonia concentrations from approximately 0 to 100 ppb NH_3-N). Use 1-cm pathlength cells if the solutions are blue (ammonia concentrations greater than approximately 100 ppb NH_3-N).

6. Prepare a series of standards from the stock NH_4Cl solution. Select at least 4 different concentrations covering the expected range of values for the samples plus a blank. Treat these standard solutions as in Steps 1 - 5. Prepare a standard curve of uncorrected absorbances versus ppb NH_3-N and determine the sample concentrations from their uncorrected absorbances.

SILICON ANALYSES

Dissolved silicon is determined spectrophotometrically by the formation of a yellow molybdosilicate complex according to the procedures described in *Standard Methods for the Examination of Water and Wastewater* (APHA 1971). Interference from orthophosphate and arsenate ions is eliminated by the addition of oxalic acid. Contamination from silica in glassware is minimized by the use of polyethylene sample and reagent containers; polypropylene pipettes, graduated cylinders, and beakers; and freshly-deionized, non-distilled water. The steps suggested for the conversion of "molybdate-unreactive silica" to "molybdate-reactive silica" by a one-hour digestion process with sodium carbonate have been eliminated, because no significant difference between these two types of soluble silicon has been found in samples of Lake Tahoe water. It has not been necessary to resort to more sensitive or more involved analytical methods that require the reduction of the heteropoly anion of molybdenum and silicon to the blue form which exhibits strong electronic absorption bands in the region from 650-800 nm. Typical reducing agents required for the latter procedures include solutions of copper (I), mercury (I), iron (II), and tin (II) salts and benzidine.

Apparatus

1. Polypropylene beakers, 100 ml, with covers.

2. Polypropylene graduate cyclinders, 100 ml.

3. Graduated polypropylene pipettes; 1 ml (1) and 2 ml (2).

4. Clock or timer.

Reagents

6 N Hydrochloric Acid –

Mix 500 ml concentrated HCl with 500 ml of freshly-deionized water. Store in an acid-washed polyethylene bottle.

Ammonium Molybdate Solution -

Dissolve 50.0 g reagent grade $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in deionized water. Dilute to 500 ml. Adjust pH to 7.8-8.1 with reagent grade pellets of NaOH. Store in a polyethylene bottle.

Oxalic Acid Solution -

Dissolve 50.0 g reagent grade $H_2C_2O_4 \cdot 2H_2O$ in deionized water and dilute to 500 ml. Store in a polyethylene bottle.

Stock Silicon Standard Solution -

A 500 ppm $SiO_3^{=}$-Si solution is prepared by dissolving 5.0595 g reagent grade sodium meta-silicate ($Na_2SiO_3 \cdot 9H_2O$; formula weight = 284.20) in freshly-deionized water in a 1000-ml volumetric flask. Because of the deliquescent nature of this solid compound, this solution must be standardized by gravimetric analysis to determine the silicon content via the weight loss as volatile SiF_4 when aliquots of this concentrated stock solution are treated with HF and heated to a constant weight at 1200°C. Store this stock solution in a polyethylene bottle.

Standard Silicon Solution -

For routine use, a more dilute standard solution is prepared. A 5 ppm $SiO_3^{=}$-Si standard solution is prepared by pipetting 10.0 ml of the stock Si solution into a 1000-ml volumetric flask and diluting to the mark with fresh, deionized water. After mixing, the solution is transferred to an acid-washed polyethylene bottle for storage. As needed, less concentrated standard solutions are prepared by dilution of this 5 ppm standard.

Procedure

1. All beakers, cylinders, pipettes, etc. should be acid-washed, deionized water-rinsed, and stored in a dust-free environment.

2. Carefully measure a 50.0 ml sample into a plastic beaker using a graduated cylinder.

3. In rapid succession, add 1.0 ml 6 N HCl and 2.0 ml ammonium molybdate solutions using the plastic pipettes.

4. Mix well and allow the solution to stand for 5-10 minutes while the yellow color develops.

5. Add 1.5 ml oxalic acid solution and mix thoroughly again.

6. Measure the absorbance of the yellow solution at a wavelength of 410 nm 5-10 minutes after the addition of the oxalic acid (the color begins to fade significantly after approximately 15-20 minutes). For concentrations below about 5 ppm $SiO_3^=$-Si, 4-cm pathlength cells should be used.

7. If two people are available, it is most convenient for one person to measure samples and develop the color while the second person measures the absorbances at appropriate time intervals.

8. Prepare a standard curve of uncorrected absorbances versus ppm $SiO_3^=$-Si from a series of four or more standards plus a blank covering the range of concentrations expected in the water samples. (These standards and blank are treated according to Steps 1 - 7). From this curve, the sample absorbances are read directly and converted to ppm $SiO_3^=$-Si. At least one sample, selected at random, should be run in triplicate for each series of determinations to provide an estimate of precision.

DISSOLVED OXYGEN ANALYSES

A modified version of the Winkler method is used to determine the concentrations of dissolved oxygen. This procedure is essentially the one described by Carpenter (1965) with the only exception being the addition of sodium azide to the sodium iodide-sodium hydroxide solution (APHA 1971) to eliminate interferences from nitrite and ferrous ion found in highly eutrophic waters such as Clear Lake.

Reagents

3 M Manganous Ion Solution -

Weigh 600 ± 1 g analytical reagent grade manganous chloride tetrahydrate ($MnCl_2 \cdot 4H_2O$) and dissolve in distilled water. Make up to 1000 ml. Manganous sulfate monohydrate ($MnSO_4 \cdot H_2O$) (516 ± 1 g) may be substituted for the former.

NaI-$NaOH$-NaN_3 Solution -

Dissolve 600 ± 1 g NaI(4 M), 320 ± 1 g NaOH, and 10.0 ± 0.1 g NaN_3 in distilled water and make up to 1000 ml. The sodium azide (NaN_3) is especially important where appreciable concentrations of Fe^{2+} or NO_2^- are believed to be present in the water samples.

18 N Sulfuric Acid Solution -

Cautiously add 500 ± 2 ml concentrated reagent grade H_2SO_4 in small portions to about 450 ml distilled water in a 1000-ml volumetric flask. Mix well and allow to cool to room temperature. Add distilled water to the 1000-ml mark and mix well.

1% Starch Solution -

Add 2.0 g soluble starch to 200 ml hot distilled water. Bring to a boil with stirring and allow to settle. Pour off the clear supernatant solution and preserve with 0.5 g salicylic acid.

0.14 N Sodium Thiosulfate Solution -

Weigh 35.0 ± 0.1 g analytical reagent grade sodium thiosulfate pentahydrate ($Na_2S_2O_3 \cdot 5H_2O$) and prepare 1000 ml of solution with distilled water. Preserve with 1 drop of carbon disulfide (CS_2). Store in a well-stoppered dark bottle.

Ampoulated 0.01000N Standard KIO_3 Solution -

Weigh 0.3567 g oven-dried (105-150°C) analytical reagent grade potassium iodate (KIO_3). Transfer quantitatively to a 1000-ml volumetric flask and dissolve in about 500 ml distilled water. Add distilled water to the mark and mix thoroughly. This solution is then sealed into glass ampoules of approximately 20-25 ml capacity which are broken open as needed to standardize the sodium thiosulfate solution.

Apparatus

1. 125-ml nominal capacity sample collection bottles with tapered glass stoppers. Bottles should be permanently labelled and their volumes calibrated "to contain" by weighing both empty and filled with water of known density. If a Teflon-coated magnetic stirring bar is to be used in titrations, its volume must be subtracted from the bottle capacity. After initial volume calibrations, stirring bars must remain in their respective sample bottles.

2. Three rapid delivery pipettes for the addition of 1.00 ml of manganous ion solution, sodium iodide-sodium hydroxide solution, and sulfuric acid solution. Calibrate to deliver 1.00 ± 0.05 ml.

3. Microburette with 2.000 ml capacity (subdivided into 0.001 ml increments) for titration of liberated iodine with 0.14 N $Na_2S_2O_3$ solution.

Procedure

1. Collect the water samples in the calibrated bottles. Place the delivery tube from the water sampler at the bottom of the collection bottle and thoroughly flush the air from the bottle by filling and overfilling with about 3 bottle volumes, being careful at all times to avoid excessive turbulence in the water stream. Replace the tapered glass stopper without trapping any air bubbles inside of the bottle.

2. Add 1.00 ml of the manganous ion solution and 1.00 ml of the NaI-NaOH-NaN_3 solution with the rapid delivery pipettes. Replace the glass stopper without trapping air bubbles.

3. Shake the bottle to disperse the precipitate uniformly. Allow the precipitate to settle at least halfway to the bottom. At this time, shake the bottles again and allow the contents to settle at least two-thirds of the way to the bottom. If desired, samples may be stored in this condition for several hours provided they are kept cold and are stored in a dark location.

4. Add 1.00 ml of the H_2SO_4 solution, and mix with the magnetic stirrer to dissolve the precipitate and release the I_2.

5. Titrate the iodine with 0.14 N sodium thiosulfate from the microburette until the brown color lightens to a straw yellow. The tip of the microburette should be submerged in the solution about 5 mm with the magnetic stirrer in operation.

6. Add about 0.25 ml of the starch indicator (5 drops) and continue the titration to the complete disappearance of the blue iodine-starch complex.

7. Record the volume in milliliters of thiosulfate solution required

for the titration. This volume is designated R in the calculations.

Standardization -

A clean sample bottle is required for this titration. Acid-rinsing a previously-used bottle followed by several distilled water rinses will remove traces of manganese. Pipette 10.0 ml of 0.01000 N KIO_3 into the bottle and nearly fill it with distilled water. Add 1.00 ml NaI-NaOH-NaN_3 solution and 1.00 ml H_2SO_4 solution. Titrate the liberated iodine as described in Steps 5-7. This volume is designated R_{std} in the calculations.

Reagent Blank -

A clean sample bottle is required here also. Pipette 1.00 ml of 0.01000 N KIO_3 solution into the bottle and add approximately 100 ml of distilled water. Add 1.00 ml of NaI-NaOH-NaN_3 solution and 1.00 ml of sulfuric acid solution and begin mixing with the magnetic stirrer. Then add 1.00 ml of the manganous chloride solution and titrate the liberated iodine with sodium thiosulfate. Record the microburette reading (X ml) having begun the titration at a reading of 0.000 ml. Then pipette another 1.00 ml sample of 0.01000 N KIO_3 into the previously-titrated solution and again titrate to the new endpoint without refilling the microburette. Record the final microburette reading (Y ml). The volume R_{blk} is obtained by subtracting the volume difference between the first and second endpoints from the volume required to reach the first endpoint:

$$R_{blk} = X - (Y - X) = 2X - Y$$

Calculations -

Dissolved oxygen (mg/l) =

$$\frac{(R - R_{blk})(V_{iodate})(N_{iodate})(\text{eq. wt. } O_2)}{(R_{std} - R_{blk})(V_b - V_{reagents})} - \text{D.O.}_{reagents}$$

where R = ml of $Na_2S_2O_3$ required for sample titration

R_{std} = ml of $Na_2S_2O_3$ required for standard titration

R_{blk} = reagent blank volume

V_{iodate} = ml of KIO_3 standard (10.0 ml)

N_{iodate} = normality of KIO_3 standard (0.01000N)

V_b = calibrated volume of sample bottle (ml)

$V_{reagents}$ = volume of sample displaced by reagents = 2.00 ml

eq. wt. O_2 = 8000 mg/equiv.

$D.O._{reagents}$ = oxygen content of reagents added (0.026 mg/l)

$$\text{Dissolved oxygen (mg/l)} = \frac{800(R - R_{blk})}{(R_{std} - R_{blk})(V_b - 2)} - 0.026$$

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